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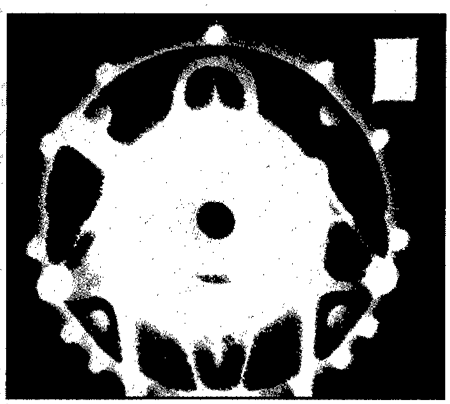

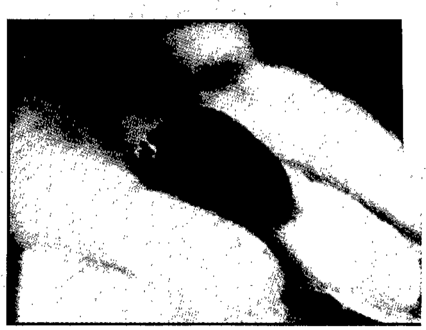

BMDO Technology and the Electric Utility Industry

A PUBLICATION OF THE NATIONAL TECHNOLOGY TRANSFER CENTER
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Abstract: This report has been written in support of the BMDO's Technology Applications program. It is intended to put those in the electric utility industry in touch with developers of highly advanced technology funded by BMDO.

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BMDO Technology and the Electric Utility Industry

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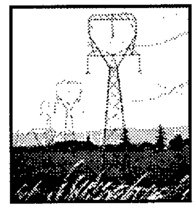
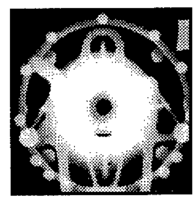
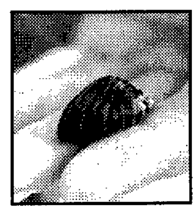
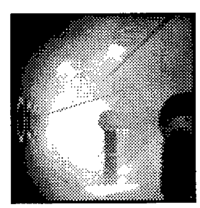
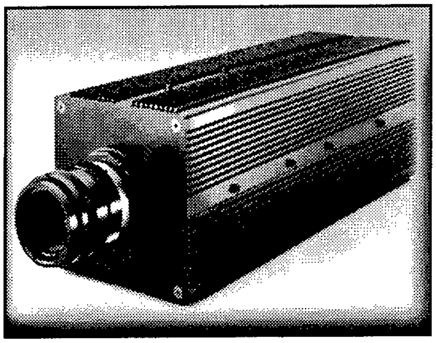
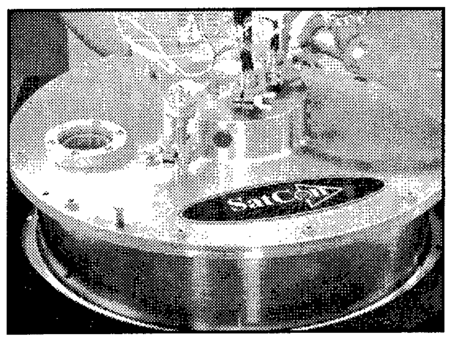












▲ *Top:* *Sensors Unlimited, Inc., page 31*

▲ *Bottom:* *SatCon Technology Corporation, page 63*

A sensor technology originally developed to track missiles becomes a device to measure pollutants in smokestack emissions. Special photoluminescent materials developed for the U.S. Department of Defense's high-speed optical computers are used to detect defects in power plant pipes. These are examples of technology transfer.

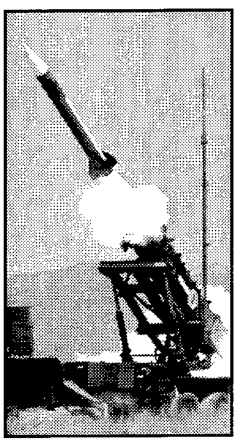
Since the early 1980s, the United States has encouraged industry to partner with Federal agencies to transfer and commercialize federally funded research and development. Tapping into the Federal resources, businesses grow, taxpayer dollars are maximized, and the Nation gets an edge in what is now a highly competitive global market. Legislation put into place the mechanisms and provided the incentives for Federal research and development programs and laboratories to actively participate in technology transfer. Examples of technology transfer activities include licensing agreements, joint partnerships, and cooperative research.

This report has been written in support of the Ballistic Missile Defense Organization's (BMDO's) Technology Applications program. It is intended to put those in the electric utility industry in touch with developers of highly advanced technology funded by BMDO. BMDO has funded a wide range of technologies that could assist electric utilities in meeting a more competitive environment. Contact information on researchers at the mentioned businesses, universities, and Federal laboratories is provided at the back of this report.

The Ballistic Missile Defense Organization:
Advanced Technology for a Strong Defense

The end of the Cold War relaxed tensions between the United States and the former Soviet Union and reduced concerns about nuclear war; however, a major new threat emerged: the spread of ballistic missile technology and weapons of mass destruction in new parts of the world. In 1994, roughly 8,800 short-range theater ballistic missiles (TBM) were in service in 32 countries. In addition, 30 new types of TBM systems are now being developed.[1]

The danger posed by this proliferation prompted a refocusing of the Strategic Defense Initiative Organization in 1993 to defend against shorter-range ballistic missiles and protect the U.S. homeland against limited missile attacks. The revised organization, called the Ballistic Missile Defense Organization (BMDO), is now responsible for designing, developing, and acquiring an integrated missile defense for the future. It focuses on three main areas:



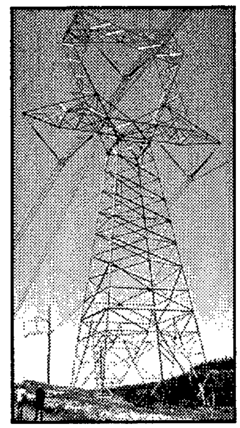
Protecting U.S. troops and allies: *BMDO is upgrading the PATRIOT missile, pictured above, which is a land-based system designed to intercept aircraft and theater ballistic missiles over a short range.*

- **Protecting U.S. troops and allies against theater missile attacks:** BMDO's theater missile defense program is designed to protect U.S. forces, allies, and other countries, including areas of vital interest to the United States, from theater missile attacks, or attacks from a relatively short range (50 to 500 kilometers). Several programs are under way in this area, including the core programs of Theater High Altitude Area Defense (THAAD), Navy Area Defense, and the PATRIOT Advanced Capability (PAC-3).
- **Protecting the United States from limited ballistic missile attacks:** Although an immediate ballistic missile attack on the United States is unlikely, the possibility of such an attack will increase as Third World countries develop or acquire simple or perhaps even sophisticated ballistic missiles. Therefore, BMDO is pursuing an R&D program to demonstrate the capability of deploying a system to protect the Nation from ballistic missile attacks. The National Missile Defense program will demonstrate a ground-based interceptor; a ground-based radar; and a battle management command, control, and communications system that comprise an initial system.
- **Investing in advanced technology to counter evolving and proliferating threats:** The Advanced Technology program allows next-generation BMD systems to draw from readily available technology solutions, such as advanced directed energy, sensor, and materials technologies. The program includes the Innovative Science and Technology (IS&T) program, which nurtures high-risk, highly advanced technology. Among many activities, IS&T also runs the Small Business Innovation Research (SBIR) and Technology Applications programs for BMDO.

[1]Ballistic Missile Defense Organization. 1995. *1995 Report to Congress on Ballistic Missile Defense.* September, p. 2-1.

The Electric Utility Industry:
Advanced Technology for a Changing Infrastructure

Since its inception at the turn of the century, the electric utility industry has been viewed as a dependable resource that provides electricity to virtually everybody in the Nation at minimal cost and with minimal interruptions. The United States is by far the biggest electricity user in the world, consuming more electricity (3,422.4 billion kilowatt-hours [kWh]) in 1993 than all the countries in Western Europe combined (2,255.0 billion kWh).[2] In addition, when compared with other U.S. industries, the electric utility sector is one of the largest, accounting for $207.7 billion in revenues from retail sales to ultimate customers in 1995.



__Increasing competitiveness:__ Advanced technologies, such as high-power electronics, may help electric utilities increase capacity over existing power lines without adversely affecting reliability.

Investors own more than 75 percent of the electric utility industry;[3] other contributors to this industry include public and independent power producers. In general, the Nation has historically viewed power providers as minimally competitive and regulation driven, with each electric utility allocating its power plant resources to its own service area. In this less-competitive climate, power producers have been able to share information about technology and techniques, knowing that any improvements are unlikely to represent a competitive threat. This climate, however, is rapidly changing.

The 1992 National Energy Policy Act (EPACT) lifted restrictions that the outdated Public Utility Holdings Company Act set in 1935. In part, the newer legislation allows investor-owned, public, and independent power producers equal access to transmission lines, introducing the realities of competition to the traditional infrastructure for selling electric power. The legislation also allows individual states to decide if customers can choose their power provider. In such cases, customers could select providers—not necessarily their local electric utility—with the best retail prices. States are divided in their approach to handle this legislation; some plan to allow industries and eventually residences to choose their provider while others have taken a more conservative approach. Nonetheless, the more competitive environment has forced electric utilities to look closer at their bottom line, while also placing a greater emphasis on customer satisfaction.

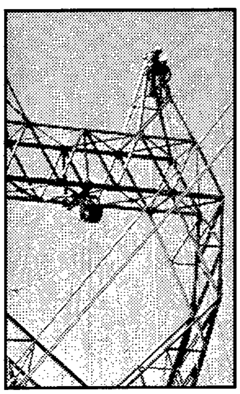
The implications of EPACT, in terms of planning in a competitive environment, presents considerable challenges to the utility industry. Customer mix, power plant type, weather conditions, fuel supply issues, and state environmental laws vary widely among utilities. For example, while coal-fired power generation stations produce 56.8 percent of electricity, a single electric utility is likely to depend on other energy generation sources as well. These sources often include uranium, natural gas, and water, but may also include some more exotic sources such as the wind or sun. The location of the power plant and the cost-effectiveness of the fuel source in that area largely determine the use of these

[2]Energy Information Administration. 1994. *International Energy Annual.* p. 84.
[3]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 1.

sources. On a side note, the Telecommunications Reform Act of 1996 may also change the shape of the power industry in another way: such legislation ultimately could put utility companies into the telecommunications business, making them all-service (telecommunications and electricity) providers.

The following bullets highlight areas where advanced technology may offer cost and performance benefits to an electric utility depending on the previously described variables:

- **Improving reliability and power quality:** As the manufacturing base increases in sophistication, its need for high-quality power also increases. Even brief power disruptions can have serious adverse economic implications. One study estimated that power outages annually cost over $3 billion to businesses, industries, and residences in the United States.[4] Electric utilities have traditionally reserved a large fraction of their transmission and distribution capacity for stabilizing electrical transmission. The industry is now seeking new technologies that increase capacity over existing lines without adversely affecting reliability. Advanced technology, such as high-power electronics, can assist in this endeavor, leading to increased customer satisfaction and reduced construction of new transmission lines.



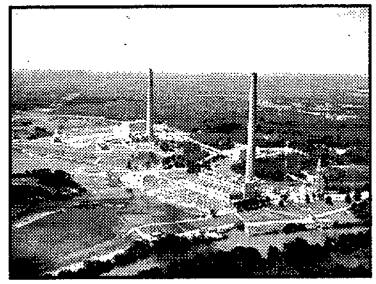
Costly cutoffs: One study estimated that power outages annually cost over $3 billion nationwide to businesses, industries, and residences.

- **Avoiding new plant construction:** By the year 2000, the projected age of the Nation's coal-fired units will average 38 years,[5] which is retirement age. Power plant managers are pursuing new strategies to extend the life of these plants, saving considerable amounts of money in new plant construction. Part of the challenge has been in providing intelligent maintenance to the aging infrastructure to optimize its life. Advanced technology, such as predictive tools, can assist plant managers determine where and when repairs must be made to prevent major damage.

- **Complying with environmental regulations:** Over 15 environmental laws on the Federal level alone affect electric utilities. Some requirements will not take effect until the turn of the century or beyond, and electric utilities are beginning to make adjustments to meet compliance. For example, one requirement stemming from the Clean Air Act Amendment of 1990 pertains to the need for continuous emissions monitoring of smokestack emissions. Another requirement calls for the reduction of nitrogen oxide and sulfur dioxide emissions from power plants.

[4]Hingorania, N. and K. Stahlkopf. 1993. High power electronics. *Scientific American*. November, p. 81.
[5]Fuldner, A. and R. Hankey. 1992. Performance optimization and repowering of generating units. *Electric Power Monthly*, August, p. 1–14.

- **Managing load demand:** Electric utilities are finding new strategies for managing loads to accomplish several goals, which the provider's customer mix and power requirements determine. Some electric utilities can benefit from load shifting technologies, which allow some electricity to be produced at night and stored for peak daytime use. Such technologies negate the need for supplemental power plants during peak periods and increase the sale of often-wasted power produced during off-peak periods. Electric utilities with a customer base approaching capacity may benefit from energy efficiency technologies that can be employed by customers, thereby eliminating the need for new construction of added capacity. In addition, other electric utilities with waning demand may encourage industrial use of electrotechnologies, which may provide environmental and other benefits to industries using this excess capacity, through the use of electrically based processing technologies.



Managing load demand: *Utilities with waning sales encourage industrial customers to invest in new electric equipment, or electrotechnologies.*

BMDO's Technology Applications Program:
Linking BMDO-Funded Technology with U.S. Industries

A power boost to the economy: *Pictured above is a prototype of The Trymer Company's noiseless solid-state generator (page 62). This device is one of many technologies that companies, laboratories, and universities are spinning off from BMDO-funded research.*

BMDO formed the Technology Applications program 10 years ago to move BMDO-funded technology to a wide variety of commercial industries. In this way, the Nation and taxpayers alike can benefit through new commercial products, industrial growth, job creation, new businesses, and quality-of-life improvements. The electric utility industry is one promising area where this federally funded technology can have a positive impact. BMDO has funded a wide spectrum of advanced technologies, while the electric utility industry has numerous technology needs due to its diverse and expansive infrastructure. This report has been written to highlight BMDO-funded technologies that can assist the electric utility industry in becoming more competitive and addresses some of the challenges that they face in this changing infrastructure.

The Technology Applications program has produced other publications highlighting related technologies that may also benefit readers interested in technologies with applications in the electric utility industry. *The Diamond Technology Initiative Report*, a 56-page report, describes 25 ongoing and recently completed projects in diamond materials. Some technologies described in the diamond report may serve in component treatment or high-power electronics. Another report, *Energy Storage Technologies*, highlights 23 BMDO-funded organizations focusing mainly on batteries and capacitors. Some of this research is being transferred to electric vehicle applications.

The Technology Applications program welcomes any questions and comments about this report, or requests for the other reports. Readers can contact us at the following:

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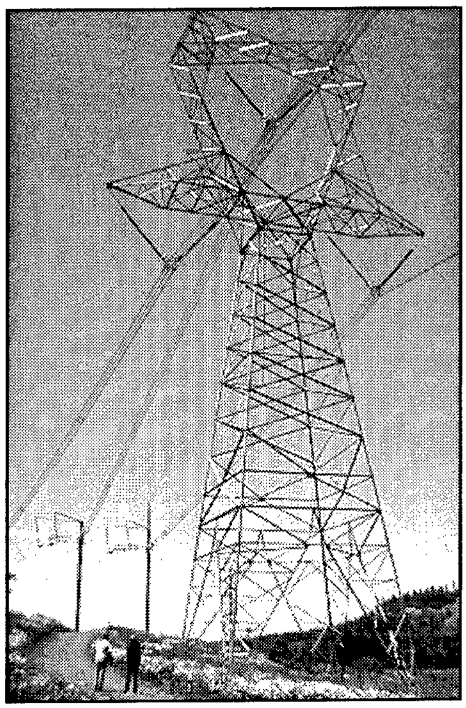


▲ ***Avoiding new construction:*** *BMDO-funded research in power electronics may offer advanced ways to protect systems from power surges, increase existing line capacity, and provide spinning reserve.*

With an intricate power grid that spans the continent, electric utilities in one region can have a major impact on power quality in other regions hundreds of miles away. For example, a July 1996 outage recently characterized this impact when a "flashover," caused by a tree in Idaho, resulted in cascading surges that led to 2 million blackouts in 15 western states, as well as Canada. While blackouts over such large regions are atypical, even minor but much more common localized power disruptions (as short as a second) can detrimentally impact the economy. In one study, Westinghouse researchers estimated that power outages annually cost over $3 billion in the United States.[1]

To prevent power disruptions and maintain power quality, utilities reserve some of their power transmission capacity to prevent or control instabilities that occur throughout the grid. By varying the voltage with transformers, transmission lines can transmit power at high voltages over long distances and distribution lines can safely deliver it at lower voltages to homes, businesses, and industries. Sudden demand fluctuations, especially when they occur through the multiple adjoining interconnections of a continental grid, can adversely affect power distribution. The power grid then becomes vulnerable to voltage and current instabilities that can cause blackouts, power surges, and power routing problems. These issues are further discussed on page 14.

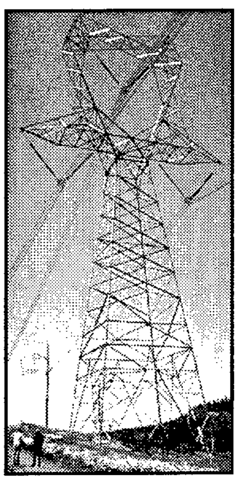
By setting aside some transmission system capacity, as well as using conventional power conditioning technologies, utilities usually have been able to address power quality problems and provide the power reliability that consumers expect. However, increasing electricity demand in many locations has presented new challenges for capacity. And moreover, the more competitive environment that deregulation presents, as discussed at the beginning of this report, has made the reliable, cost-effective, and energy-efficient use of transmission and distribution systems imperative to the industry. This chapter addresses several applications for utility transmission and distribution systems in which BMDO-funded technologies offer potential solutions. It covers the following subjects:

- Improving Capacity, Security, and Power Switching
- Protecting Lines from Power Surges
- Using Energy Storage Systems for Power Stability
- Detecting Downed Power Lines
- Predicting Solar Flares
- Installing Underground Power Lines

[1] Hingorania, N. and K. Stahlkopf. 1993. High power electronics. *Scientific American.* November, p. 81.

Improving Capacity, Security, and Power Switching

Between 1993 and 2010, officials predict that the demand for electricity will rise by over 30 percent.[2] But the advent of deregulation has transformed power production into a much more competitive industry. Electric utilities face new decisions in their attempt to provide additional power in a cost-effective manner as they strive to likewise improve existing power quality for their customers. They are caught in a dilemma: they have been sticker-shocked by the exorbitant costs associated with building new transmission lines. And electric utilities have been discouraged by neighboring communities to build new lines, in light of aesthetic concerns and questionable electromagnetic frequency (EMF) health effects. Yet they are aware of the increasing demands on existing transmission systems, which, without advanced technology or new construction, may introduce power quality problems affecting customers.



Power switching: *FACTS is a concept to improve capacity, security, and power control of transmission systems. Technologies such as the MOS-controlled thyristor are being investigated for FACTS systems.*

As the utilities approach their capacities, even small mismatches in voltage and current cycles can cause instabilities. When these mismatches and instabilities occur, they decrease the power grid's efficiency and sometimes cause current to flow through out-of-the-way channels, such as other states. In extreme cases, an instability can shut down a system and quickly domino into a whole power grid blackout.

Addressing power stability issues, organizations such as the Electric Power Research Institute (EPRI) have been investigating a concept called flexible alternating current transmission systems (FACTS) to improve the power control, capacity, and security of transmission lines. Able to switch current within a fraction of a cycle, these small electronic systems can rectify problems associated with impedance, voltage, current, and phase angle much better than the massive electromechanical devices used today. The older systems can take several cycles for switching on and off. Central to FACTS are advanced power electronics to control the flow of current over the transmission lines.

Funding Technology Innovations

BMDO-funded research in power control for directed energy weapons led to a high-power semiconductor device called the metal-oxide-semiconductor (MOS)-controlled thyristor, or MCT, being developed for use in FACTS. This highly advanced variable switch could significantly increase the capacity of transmission systems by controlling voltage, current, phase angle, and impedance. It can switch in a small fraction of an alternating current (ac) cycle to control the flow of electrical current, greatly reducing power interruptions associated with cumbersome mechanical devices. MCTs may quickly reroute power to prevent major electromagnetic disturbances from causing outages.

BMDO also funded research to produce an emerging class of semiconductor materials that are better for high-power switching applications when compared to silicon. These wide-bandgap semiconductors include silicon carbide (SiC), gallium nitride (GaN), aluminum

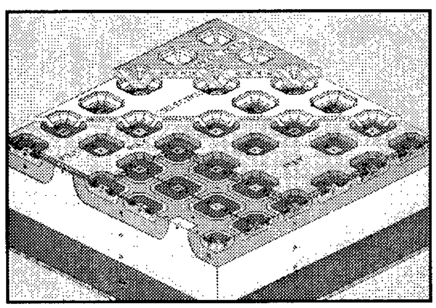
[2]Energy Information Administration. 1995. *Annual Energy Outlook 1995*. January, p. 24.

nitride, and diamond. Because these materials have a wide energy bandgap, heat and other external influences do not readily disrupt their performance. (A wide bandgap is a semiconductor property that determines the amount of energy needed to make the material carry current.) Electronic devices made from these materials can operate at higher power levels, temperatures, and radiation levels than silicon- and gallium arsenide-based devices. While promising, the technology for producing device-quality wide-bandgap semiconductors is still in its infancy, and widespread use in the utility industry is several years away. Of the wide-bandgap materials mentioned above, silicon carbide is the closest to commercialization.

Moving the Technology to Market

■ Harris Semiconductor Corporation

Harris Semiconductor Corporation (Melbourne, FL) acquired rights to the MCT, which was developed partially under BMDO sponsorship by General Electric Company's power electronics division. This device is more rugged, reliable, and efficient than conventional power semiconductor devices. With U.S. Navy and Defense Advanced Research Projects Agency (DARPA) funding, Harris Semiconductor and EPRI are addressing further development and packaging requirements for high-power MCTs. The team will package MCTs with semiconductor rectifiers and high-performance "smart" gate-driver integrated circuits to form power electronic building blocks (PEBBs) that are much smaller and more powerful than conventional power control modules. In addition to working with much higher current and voltages, the Harris/EPRI-developed PEBBs perform with lower internal resistance. With advanced power electronic devices such as these, utilities could save as much as $6 billion through higher efficiencies in switching, benefiting from the extended power-handling capacity.[3] Other organizations including NASA, General Electric, Westinghouse, and AlliedSignal also funded the development of this technology.



The potential is billions and billions: *The MOS-controlled thyristor is more rugged, reliable, and efficient than conventional power semiconductor devices. With advanced power electronic devices such as these, utilities could save as much as $6 billion through higher efficiencies in switching.*

Harris Semiconductor released its first line of MCTs, a 600-volt p-type MCT, in September 1992. It since added three more MCT devices, which include one 1,000-volt, 65-ampere p-type MCT as well as two 35-ampere devices, one with and one without a built-in diode. The company expects soon to release a 6,000-volt, 75-ampere device in a second generation of MCTs. The latest device will offer a four-fold improvement in switching speed over current generation devices. The company recently built a $250 million power semiconductor manufacturing facility to construct a MOS 8-inch wafer fabrication facility for MCTs, MOS field-effect transistors, and insulated gate bipolar transistors.

[3]Hingorania, N. and K. Stahlkopf. 1993. High power electronics. *Scientific American*. November, p. 85.

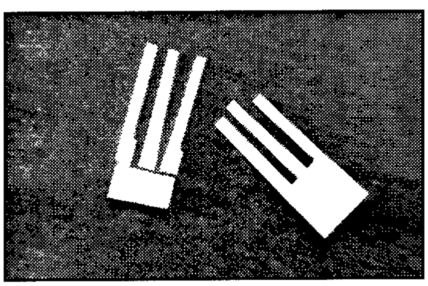
■ Cree Research

Researchers at Cree Research (Durham, NC), with BMDO funding, are developing SiC wide-bandgap semiconductors. Striving to make defect-free, single-crystal SiC wafers, they are overcoming some of the technical barriers that traditionally prevented widespread use. These barriers include the high temperatures at which SiC must be formed, SiC's resistance to chemical treatment and cutting, and its tendency to crystallize in over 100 different atomic arrangements. Over the years, Cree steadily lowered the defect density and cost of its SiC wafers. As one of its high-power inventions, the company demonstrated the first vertical power metal-oxide-semiconductor field-effect transistor (MOSFET) made from SiC.

Cree formed a DARPA-financed partnership with Motorola, General Electric, and Honeywell to develop high-power and high-temperature SiC electronic devices. The group will also increase the diameter of the SiC wafers that can be grown. In recent years, wafer size has increased from 1 to 2 inches, and may soon approach 3 inches.

■ Astralux

Astralux (Boulder, CO), with BMDO-funding, developed the first transistor that can operate above 500°C with a current gain exceeding 100. In comparison, the maximum operating temperature of conventional silicon transistors is 150°C. Astralux's wide-bandgap heterojunction bipolar transistor (HBT) is made from GaN and SiC.



Taking the heat: *Astralux's high-temperature transistors could be used for switching in FACTS and battery storage applications.*

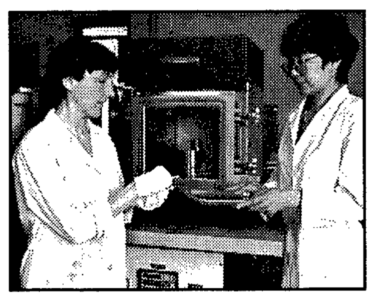
In addition to FACTS, electric utilities could use these transistors for fast switching in energy storage applications and parallel combinations One approach for energy storage at utilities is to connect large batteries in series; however, when one battery malfunctions, the batteries in parallel with the bad unit dump their charge into the defective battery. Astralux's HBTs can monitor and instantly switch off any malfunctioning battery, allowing the system to operate. The HBT's ability to withstand high temperatures is crucial to this application since these batteries are most efficient at 350°C. The technology also can serve as an inverter, switching power from direct current to alternating current (dc to ac), which is especially important for energy storage applications because batteries produce dc. Astralux plans to offer devices commercially as soon as the company starts a pilot line. The Navy has funded successful follow-on research to address electronic packaging issues through an SBIR contract.

Protecting Lines from Power Surges

Because of their complexity, utility grids frequently experience abrupt surges in power transmission, or fault currents, often caused by lightning strikes and equipment short circuits. Utilities generally protect their grids from power surges using two methods: (1) by aggressively designing equipment and instruments to allow for much excess capacity, a costly and cumbersome approach, or (2) by using inductors, which produce waste heat, dissipate electricity, and require ventilation.

Funding Technology Innovations

Through the SBIR program, BMDO funded work in devices called superconducting fault current limiters, which can protect equipment from power surges. BMDO primarily developed them for space-based power applications. The fault current limiter is based on the characteristics of high-temperature superconductors. When an electrical current is less than the threshold value, cryocooled superconducting materials conduct the electricity with virtually no resistance. But if the superconducting component receives a power surge beyond its current-carrying capacity, just the opposite happens; it acts as a resistor and suppresses the surge.



Stopping the surge: *Two researchers, pictured above, at Illinois Superconductor Corporation fabricate HTS components. The company has developed an HTS fault current limiter that, at an electric utility site, would be much faster than conventional methods for surge protection, while also generating less heat than inductors.*

Moving the Technology to Market

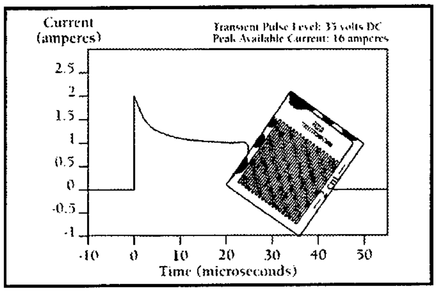
▪ Illinois Superconductor Corporation

Illinois Superconductor Corporation (ISC; Evanston, IL) is using high-temperature superconducting (HTS) materials to control electrical current surges. Its BMDO SBIR-funded superconducting switch, or fault current limiter, is nearly one thousand times faster than a conventional protector and can shut off an electrical surge in less than one millionth of a second.

In ISC's technology, an HTS fault current limiter is placed in parallel with a conventional resistor. In normal operation, most of the current flows through the low-resistance HTS switch while the resistor carries only a small fraction of the current. When a power surge exceeds the current capacity of the HTS switch, the switch becomes resistive rather than superconducting. Because the HTS switch has shut down, the only current path remaining is through the resistor, which suppresses the surge. The HTS fault current limiter quickly returns to its superconducting state and resumes the current load once the surge conditions have abated. If installed at a utility site, ISC's HTS fault current limiter would be faster than conventional methods for surge protection. In addition, it should generate significantly less heat than inductors and dissipate less electrical energy in-line.

■ IAP Research, Inc.

IAP Research, Inc. (Dayton, OH) also developed a high-temperature superconducting (HTS) fault current limiter, funded through a BMDO SBIR contract. This 20 mm^2 solid-state device uses a "foldback" design, serving as a circuit breaker. In this design, the HTS component acts as a resistor and shuts off the current when current flow exceeds capacity. Acting like a resettable fuse, the fault current limiter then quickly superconducts again after the excessive voltage is removed.



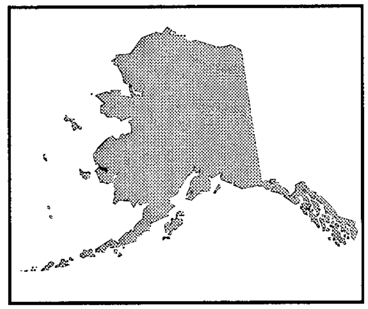
Microsecond response time: *A 35-volt pulse applied to a fully conducting IAP Research HTS fault current limiter resulted in less than 2 amps across the limiter in less than a microsecond.*

In tests, IAP Research used a design with a critical current of 2 amperes and a blocking capability of 35 volts (V). It turned off current in submicroseconds and turned it back on in tens of microseconds. This technology performs much better than high-speed fuses, which conduct three to four orders of magnitude more fault current than IAP's device. Operating below the critical current, IAP's fault current limiter also demonstrated less than a 0.5 V drop when inserted into the systems. The technology can also be designed for limiting other current levels and blocking voltage, and can be used for ac and dc power circuits. IAP expects that the device will be able to block up to 1,000 V.

Using Energy Storage Systems for Power Stability

As previously noted, advanced flexible alternating current transmission systems (FACTS), through fast power electronics, offer several advantages for electric power transmission and distribution. For example, they can increase transmission line capacity, improve power stability, and avoid cascading power outages.

However, until recently, FACTS designs lacked energy storage systems, which further improve power stability. Mid-sized storage systems allow transmission systems to rapidly absorb excess power from surges. And, serving as a source of spinning reserve (excess power online), they then can inject power back into the system as needed to maintain frequency during power disruptions. Often provided by less-used power generating facilities, spinning reserve has been an issue for electric utilities. For example, a utility in Alaska, as discussed below, has been seeking ways to reduce the use of costly natural gas-generated power for spinning reserve and has made capital investments to lower such costs.



North to Alaska: *Babcock and Wilcox is working with Anchorage Municipal Light and Power on the first commercial mid-sized SMES unit.*

Highlighted below is a technology that contributes to energy storage for FACTS. It should be noted that energy storage technologies, when scaled up to larger capacities, have other benefits, such as load leveling, highlighted on page 70. If engineers build them on a large scale, technology described in this section also may level power loads; however, current projects focus on increasing stability for power transmission.

Funding Technology Innovations

To provide sudden bursts of energy for a free-electron laser, BMDO, in conjunction with the Electric Power Research Institute (EPRI), funded two design concepts of a large-scale superconducting magnetic energy storage (SMES) system. SMES stores energy in a magnetic field produced by circulating current in superconducting coils. The coils are charged and discharged through a solid-state power converter; a cryogenic system keeps them extremely cold (4.5 K, or about –450°F). Because it is a superconductor, SMES can potentially store electricity for long periods and discharge power with 95 percent efficiency and millisecond response times. Its ability to inject or absorb active power so rapidly allows it to serve either in part or exclusively as a FACTS. Its importance and capabilities in this role recently led engineers to officially label SMES as a FACTS device.

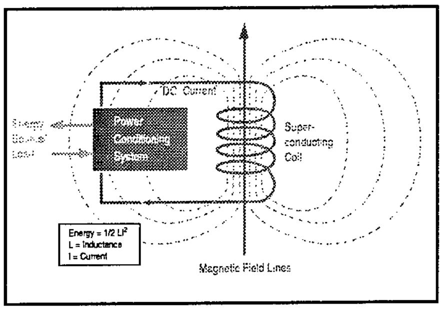
Moving the Technology to Market

■ Babcock and Wilcox

Babcock and Wilcox (Lynchburg, VA) is working with Anchorage Municipal Light & Power (AML&P; Anchorage, AK) on the first commercial mid-sized SMES unit, projected to be completed in 1999. The above-ground, low-temperature (4.5 K) storage system will provide numerous advantages to Alaska's 600-mile railbelt electrical inter-tie, which runs from Fairbanks through Anchorage to Homer. The SMES system will correct generation and transmission disturbances, provide voltage support, and supply spinning

reserve (or online reserve). The system will store 1,350 megajoules and deliver active and reactive power up to 30 megavolt amperes.

AML&P expects that the SMES system will replace much of the costly natural gas-generated power used for spinning reserve; if power generation capabilities of primary plants are lost, the SMES system can inject active and reactive power to support frequency until a hydroelectric power facility increases its output to compensate for the disturbance. The system can thereby prevent power outages caused by load shedding. (In load shedding, utilities disconnect parts of an electric power system to prevent the entire system from failing from power overloads.) And, because of the added efficiency and improved power transmission performance, SMES should also offer cost and environmental advantages. According to studies at Oak Ridge National Laboratory, the SMES unit should save $2 million per year in fuel and avoided power disruptions for AML&P. Including the six neighboring utilities in the railbelt inter-tie system, the savings could double. In addition, increased efficiencies will reduce the amount of pollution that power plants emit in the Alaska region.



***How it works:** SMES stores energy in a magnetic field produced by circulating current in superconducting coils. Its ability to inject or absorb active power with millisecond response times makes it ideal for FACTS.*

The Defense Advanced Research Projects Agency's Technology Reinvestment Project partially supported the development program. While the design of the system differs from the initial design concepts developed through the BMDO–EPRI-sponsored project, the early activity in the joint project stimulated the research efforts of B&W. Other participants include Virginia State University, the U.S. Department of Energy (DOE), Argonne National Laboratory, Norfolk State University, St. Paul's College, and the University of Alaska. The U.S. Navy is also providing funding.

In the BMDO–EPRI project for large-scale SMES, called the Engineering Test Model (ETM), Bechtel and EBASCO designed two different pilot plants. This work was based on previous research that DOE, Wisconsin utilities, Bonneville Power Administration, Bechtel, the University of Wisconsin, and EPRI conducted. The two design concepts shared similarities. For example, the two teams designed test models that, when built, could store 20 megawatt hours (MWh) of energy and supply 400 MW of peak power, exhibiting the capabilities of a small power plant. And with 100-meter diameters, both units were continuously wound solenoids using low-temperature niobium-titanium (Nb-Ti) superconducting materials cooled by superfluid helium. Also, the units were to rest in trenches about 10 meters deep and 5 meters wide to support the Lorentz force, exerted by current passing through a magnetic field.

The Defense Nuclear Agency (DNA) and DOE have further researched military and utility applications, and, in fiscal year 1994, large-scale research was transferred from DNA to the U.S. Navy. The U.S. Navy and EPRI are working with new teams to develop design concepts of mid-sized units that will store between 0.1 and 1.0 MW of energy. The Navy is funding these concepts for weapons systems on large military ships and EPRI is funding this work for power conditioning at electric utilities. The Navy is also building a facility to test and fabricate major conductors that SMES will use.

Detecting Downed Power Lines

With a complex grid extending through rural, suburban, and urban areas, utilities often have difficulty locating distribution lines and often must wait for the customers to call their service provider with such information. This lack of information slows the ability of utilities to restore power. And, the delays in power restoration present serious hazards to those traveling near the downed lines as well as greater economic loss for businesses and industry.

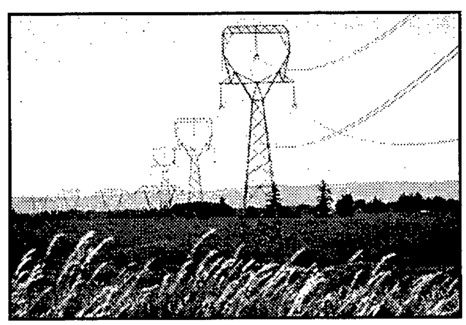
Funding Technology Innovations

Finding solutions to track ballistic missiles electronically, BMDO funded algorithms that can lock onto one signal, even in a crowded environment of multiple signals, and continue to track it. When modified for utility use, this technology can almost instantaneously detect downed power lines, improving repair efficiency and customer relations.

Moving the Technology to Market

■ University of Rochester

Researchers at the University of Rochester (Rochester, NY) originally developed the congruential coding algorithm for BMDO to increase the number of channels in multiuser radar and spread spectrum communications systems. Subsequently, the university won a $300,000 contract with the Rochester Gas and Electric Corporation (RG&E) to develop an alarm system to detect downed power lines using this technology.

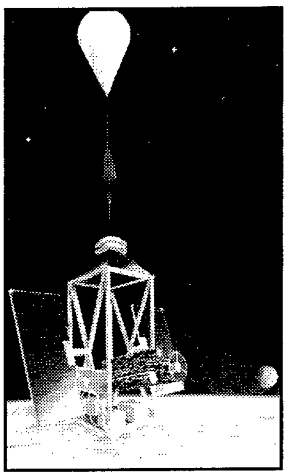


When lightning strikes: *Rochester Gas and Electric Corporation pursued an advanced algorithm developed at the University of Rochester to automatically detect downed power lines.*

If fully developed, penny-sized transmitters could be built right into the porcelain insulators that sit on power lines. These transmitters would then detect line and equipment failures and transmit this information to the emergency center of a power distribution network. With traditional technologies, it is difficult to transmit many signals or discriminate among simultaneously transmitted signals in adverse conditions. However, the University of Rochester's technology could recognize the unique digital address of each signal, or unique codes, and sort the signal from electronic noise and link them with particular transmitters. It thereby would allow a computer at the utility's emergency center to track the codes; if one vanished, an alarm would sound. Therefore, using this coding technology, personnel at RG&E could locate line and equipment failures more accurately within the utility's service area.

Predicting Solar Flares

Solar flares cause magnetic storms that can cost utilities millions of dollars because of associated power surges. These storms usually occur in multiyear cycles after a sunspot maximum. (A sunspot maximum is the time in the solar cycle when the number of sunspots reaches a maximum value.) Causing electrical potential differences in the earth's surface, sunspots result in excessive direct current (dc) flows in power transformers, devices that step up the alternating current (ac) power voltages for transport over long distances, and then step voltages back down for safe distribution to customers. High current flows, resulting from the solar flares, can overheat the transformer, degrading the insulation and causing the transformer to fail.



Riding out magnetic storms: *The Flare Genesis Experiment, illustrated above, could warn electric utilities about solar flares four days ahead of time.*

The extent of damage that solar flares cause was demonstrated in March 1989 after a major solar flare incident, which seriously affected the eastern portion of North America. A severe magnetic storm event badly damaged a generator step-up transformer for a nuclear generating station in the Northeast. The transformer failed and the power plant ceased to transmit power for roughly three months. Another transformer in Canada was also affected, causing a major blackout in its service area.

While scientists and engineers cannot stop sunspots and solar flares, they may be able to predict such phenomena days ahead of time, with the right technology. This ability could allow utilities to reduce the load on critical transformers so that the components could handle power surges and utilities could avoid costly damage. Current technology warns utilities about solar flares only minutes ahead of time.

Funding Technology Innovations

BMDO built a space-rugged telescope with an 80-cm mirror to be deployed in extra-atmospheric military applications. This telescope is now being used to study solar flares and storms. If used continuously, the telescope could warn utilities about solar flares 4 days ahead of time.

Moving the Technology to Market

■ Johns Hopkins University's Applied Physics Laboratory

While no *commercial* efforts have resulted, researchers at Johns Hopkins University's Applied Physics Laboratory (JHU APL) have used the BMDO-funded telescope in a study called the Flare Genesis Experiment. This study is yielding information about the origin and predictability of solar flares, sunspots, and associated "storms" of electromagnetic radiation. The team lofted the instrument in a balloon about 40 kilometers above Antarctica for a 19-day, circumpolar flight in January 1996. The Austral summer season allowed continuous viewing of solar features during this time. Data have been collected and are being analyzed.

The telescope being used in this project has one of the largest available mirrors for viewing solar phenomena. Measurements of the sun's magnetic field are made with a JHU-developed magnetograph. Visible records of sunspots and solar flares are made with the help of a "silicon retina" developed at JHU APL. This device allows the telescope to lock onto the finest structures on the solar surface for precise measurement.

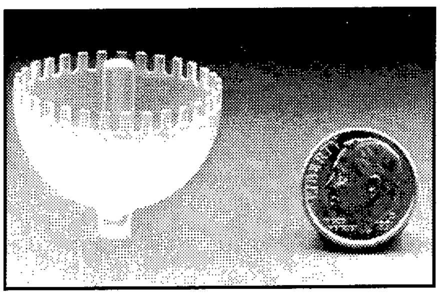
Early warning could give power plant operators more time to prepare for solar flare incidents.

The body of the telescope is made of a graphite-epoxy fiber, and the honeycomb-structured mirror is made of ultra-low-expansion glass. Both materials are very lightweight and are thermally stable, helping to ensure ruggedness and ease of recovery after the flight. The thermal stability of the mirror also diminishes temperature-induced wavefront errors, which reduce image quality. Heat from solar energy incident upon the mirror was efficiently transferred with heat pipes into a receiving radiator attached to the outside of the telescope, another technology applied from space-system developments.

Electric utilities could benefit from the information provided by such a telescope. They would have days to prepare for solar flares. In this way, major failures could be more easily avoided.

Installing Underground Power Lines

Overhead power lines have become increasingly difficult to build. Planners face problems such as obtaining rights-of-way, preventing further congestion, and maintaining aesthetics in urban and suburban areas. Therefore, many utility planners have selected pipe-type cables underground. Despite their much higher cost, which ranges from 8 to 20 times that of overhead power lines, underground pipe-type cables address many power issues in new developments and renovations. Roughly 2,500 circuit miles of electric utility pipe-type cables have been installed in the United States.[4]



Tunneling underground: *The Hemispherical Resonator Gyro, pictured above, can provide the precision needed for trenchless drilling systems used to install underground power lines.*

One way to install and repair underground cables is to use trenchless technology. With trenchless technology, as its name implies, installers bore underground tunnels horizontally instead of digging trenches at the surface. This approach prevents traffic and business disruptions normally associated with trenching. A challenge that utilities face in urban areas is in finding trenchless methods that operators can quickly and precisely steer to avoid other underground infrastructure such as gas lines, water mains, and telephone cables.

Funding Technology Innovations

Addressing needs for space-based ballistic missile defense, BMDO funded work in compact, highly rugged gyroscopes, used to maintain an angular reference direction to "remember" where the horizon is. One design evolved into a small, highly precise quartz device using sound waves. Industry is incorporating this technology, called the Hemispherical Resonator Gyro (HRG), into a high-precision trenchless drilling system.

Moving the Technology to Market

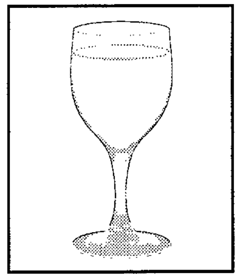
■ Litton Guidance and Control Systems

Using the BMDO-funded HRG, Litton Guidance and Control Systems (Goleta, CA) is working with a major corporation in the oil industry to develop a horizontal drilling tool that can reduce the time and costs for drilling, while increasing precision. In particular, the two companies are developing a system based on measurement while drilling (MWD) techniques. MWD uses a cylindrically shaped sensor package (containing the gyro) roughly 2 inches in diameter, which is connected to the drill string. MWD techniques also use accelerometers, a power supply, an electronics processing package, and a telemetry package. The drill string has a drill bit at the end, which a mud-driven motor operates.

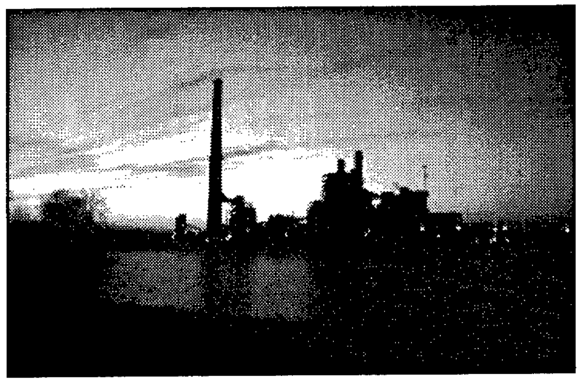
[4] Electric Power Research Institute Power Delivery Group. 1996. Underground transmission target. Internet. [http://www.epri.com/pdg/trans/trans_ut.html].

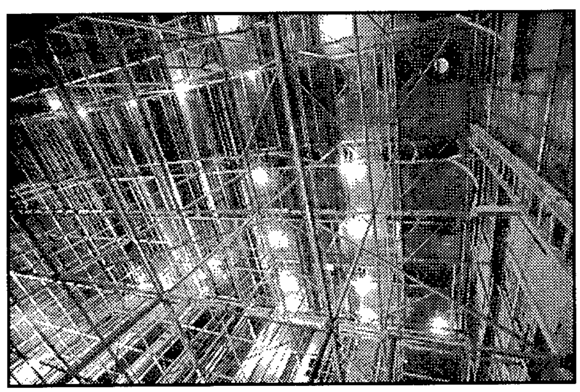
The HRG is sometimes called the wine glass gyro because in 1890, physicist G.H. Bryan used a wine glass in an experiment that led to HRG development. Bryan rubbed his finger around the rim of the wine glass, which then rung. He observed that by rotating the stem of a ringing wine glass, the standing wave pattern of vibration precesses (slowly turns) at a constant rate around the bowl of the glass. Based on Bryan's observations, the HRG senses rotation with a single vibratory wave, continuously computing the inertially induced precession angle between the standing wave and the gyro case.

Because the fused silica resonator has an extremely high-Q (efficiency) resonance, the HRG is very precise. It can achieve a random walk of only 0.0007 degrees per root hour. With a weight of about 130 grams and a volume of 80 cubic cm, this device is lighter and smaller than similar technologies for comparable applications. The HRG requires only microwatts of power as opposed to other gyro technologies, which require over 1 watt. It is also highly rugged and is unaffected by radiation or short-term power outages.



HRG beginnings: *Rubbing his finger around the rim of a wine glass, G.H. Bryan made observations that led to HRG development.*





▲ *Top:* ***An aging infrastructure:*** *By the year 2000, the average age of the Nation's coal-fired units will be 38 years, according to the Energy Information Administration.*

▲ *Bottom:* ***Keeping power plants functional:*** *BMDO has funded a wide variety of technologies for predictive maintenance, able, for example, to detect defects in a plant's vast array of pipes and other components.*

Fossil fuel power plants, including those generating electricity from coal, natural gas, and petroleum, account for the lion's share of the United States' generating capabilities, offering 72 percent of total power capacity and producing 69 percent of the Nation's electricity.[1] These power plants not only represent a large part of the utility infrastructure, but, unfortunately, an aging part of it as well. In the past, utilities usually retired and replaced fossil fuel power plants after about 30 years of operation; however, due to economics and other factors, managers have changed their strategies, extending plant lifetime through incremental improvements. By the year 2000, the average age of the Nation's coal-fired units will be 38 years, gas-fired units will be 42 years, and oil-fired units will be 47 years.[2] Advanced technologies used in these older power plants can assist electric utilities in their plight to avoid new construction costs; two examples of areas where such technologies can help are in predictive maintenance and optimization of plant operations.

Predictive maintenance tools detect defects and damage early on, allowing power plant engineers to repair parts before damage becomes severe. In addition, such tools facilitate the ability to make repairs during routine downtimes, preventing unscheduled and costly downtime for the plant. Such tools can save utilities millions of dollars in maintenance costs, which account for an average of 13 percent of a utility's operating budget.[3] For example, in a comprehensive study of predictive maintenance conducted by the Electric Power Research Institute (EPRI), PECO Energy Corporation (Philadelphia, PA) estimated that its Eddystone power plant will save $1 million over five years through capital savings and avoided maintenance costs on electric motors alone.[4]

In addition, electric utilities can optimize fossil fuel power plant operations through advanced computational software and sensor technologies. Such technologies can provide prediction, monitoring, and control capabilities for power plants, allowing them to operate more efficiently, with less pollution, thermal stress, and breakdowns.

BMDO funded research in nondestructive evaluation techniques, thermography, neural networks, software, and advanced sensors to locate, track, and destroy ballistic missiles. This research may also find applications in the utility industry's fossil fuel power plant infrastructure. Some technologies serve as predictive maintenance tools, others improve plant operational performance, and still others can serve as both. This chapter highlights some of these technologies in the topic areas highlighted below:

- Using Nondestructive Evaluation and Thermographic Tools
- Employing Advanced Sensors
- Monitoring and Controlling Plant Processes
- Predicting Plant Response for Higher Efficiencies

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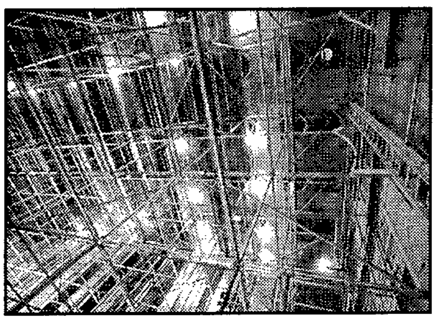
[1]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume I.* July, p. 5.
[2]Energy Information Administration. 1992. *Electric Power Monthly.* August, p. 14.
[3]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 36.
[4]Douglas, J. 1995. The maintenance revolution. *EPRI Journal.* May/June, p. 13–14.

Using Nondestructive Evaluation and Thermographic Tools

When power plant equipment is damaged, technicians must sometimes remove an entire generation unit from service, resulting in added costs from unscheduled plant downtime. Therefore, many utilities are implementing or investigating advanced predictive maintenance tools to improve plant management.

Predictive maintenance tools are advanced diagnostic systems that can quickly (often in real time) detect minute component flaws that could eventually lead to much bigger problems in power plant operation. Such systems include nondestructive evaluation (NDE) and thermographic devices. Using the diagnostic information that NDE and thermography tools provide, plant operators can develop "intelligent" maintenance schedules to correct damage or flaws with minimal impact on plant operations.



Pipes and more pipes: *Using nondestructive evaluation technologies, plant technicians can detect flaws within power plant pipes. This capability allows flawed parts to be fixed during scheduled downtimes, before damage causes serious problems.*

NDE tools allow technicians noninvasively to view the material condition inside a component. Such techniques can, for example, help power plant operators identify pitting, corrosion, and cracks in the extensive array of pipes so that technicians can correct these problems at an early stage, during scheduled downtimes, before the pipes burst or leak. Advanced portable thermographic tools (sometimes regarded as a subset of NDE tools) offer similar advantages for utilities by imaging variations in heat through infrared imaging. They can be used, for example, in motors to detect excessive heat, a condition that may indicate clogged air filters, abnormally high current flow, or elevated bearing temperatures.

Funding Technology Innovations

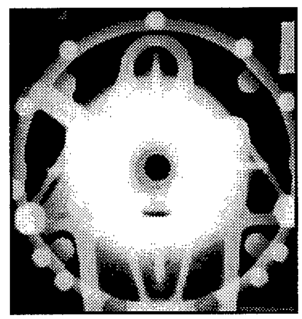
BMDO has funded several projects leading to NDE techniques that power plant technicians can use for predictive maintenance. For example, through its SBIR program, BMDO funded research on a special class of photoluminescent materials for high-speed optical computers used in ballistic missile defense. Engineers have applied developments in this area to a diagnostic system that views the inside of power plant components.

Other research that can be applied to diagnostic testing for electric utilities includes (1) a portable x-ray system to diagnose components derived from a BMDO-funded project called Satellite Attack Warning and Assessment Flight Experiment (SAWAFE); (2) a technique called diffraction moiré, which BMDO originally funded to measure transient phenomena such as the stresses produced on a missile body during re-entry; and (3) a portable infrared camera, funded to track ballistic missile plumes in space.

Moving the Technology to Market

■ Quantex Corporation

Quantex Corporation (Rockville, MD) developed Electron Trapping (ET)™ materials, through the BMDO SBIR program among other sources, which are key to a solid-state radiography system used for NDE of electric utility components. To capture radiographic images, Quantex has replaced conventional x-ray film with a new kind of reusable, more sensitive solid-state film using the ET materials. (A technical description of ET materials is provided below.) ET technology eliminates or greatly reduces many of the problems normally encountered with film radiography: it reduces required radiation; eliminates film processing chemicals; and allows images to be electronically archived, transmitted, and enhanced.



Detecting minute flaws: *One of RADView's advantages is that it reduces the amount of radiation normally required to produce an image, dramatically reducing the size of rope-off areas for workers. Pictured above is a RADView image of a flywheel device.*

Quantex licensed the ET-based technology to Liberty Technologies, Inc., which incorporated the film into a system called RADView™, now marketed by Liberty. In near real time, RADView noninvasively detects minute flaws or defects inside objects such as power plant pipes and valves. Initially tested at Virginia Power, RADView is being used in several electric utility applications and is particularly useful in ongoing erosion, corrosion, and critical valve monitoring.

The system rapidly captures and digitizes radiographic images, which technicians view and enhance electronically to extract a much greater range of information from the images, including quantitative analysis. Digitizing the image information during readout allows direct input to computer systems. RADView also captures latent images with wider dynamic range at lower x-ray or gamma doses than conventional film systems.

Because this device has wide dynamic range and digital analysis capabilities, technicians can learn information about pipe wall thinning or valve operation by direct visualization through radiography. Built-in analysis tools allow technicians to measure pipe wall thinning quantitatively so that long-term trends can be predicted to improve power plant reliability and reduce operating costs. And since it reduces the radiation normally required, RADView can dramatically reduce the size of rope-off areas for workers, increase the number of online inspections for power plants, and subsequently lower costs of operations for the electric utility.

The system also addresses long-term archival requirements, because many utilities must maintain radiographic records for the life of the facility or for 40-plus years. While conventional radiographic films begin to degrade after roughly 10 years, Liberty's digital images can be electronically archived (at relatively low cost) on optical media for around 100 years without losing information.

The technology behind RADView, Quantex's ET material, is a special class of photoluminescent material that converts incident light or radiation into local populations of excited electrons. The material "traps" excited electrons for long periods until a readout beam of less energetic photons (in the near-infrared spectrum) releases them. When the trapped electrons are read out, a visible light pattern is produced, which duplicates the

original incident image. The exact design and performance of ETs varies depending on the application, which may be in optical computing, infrared sensing, or radiographic imaging. When designed for nondestructive inspection of power plants, a layer of ET material captures a latent radiation image and stores it. The material is then exposed to infrared light, which releases the image as visible-wavelength light.

Quantex has also received support for its work in ET materials from the National Cancer Institute, NASA, the National Institute for General Medical Sciences, the U.S. Air Force, the U.S. Army, the National Institute for Dental Research, and the Naval Surface Warfare Center.

■ Golden Engineering, Inc.

Golden Engineering, Inc. (Centerville, IN), has developed and is marketing a small lightweight x-ray system for NDE ideal for uses in which portability is important; the electric utility industry shares this need. When transporting conventional large x-ray systems, technicians must move hundreds of pounds of equipment. Golden's entire x-ray system—including pulsed power source, battery pack, remote cable, intensifier screens, instant type x-ray film, and film developing unit—fits into one carrying case and weighs just 30 pounds. Despite its small size, the pulsed device has a 150,000-volt peak output that will penetrate a 1/2-inch thickness of steel.

***When portability is important:** Golden Engineering's x-ray system weights just 30 pounds and costs less that $5,000 per unit.*

The power supply for the pulsed device is a 7.2-volt removable, rechargeable nickel-cadmium battery pack that fully recharges in one hour. The battery can provide up to 2,500 x-ray pulses per charge, each lasting 60 nanoseconds. To use the device, operators attach the battery, set the desired number of pulses, and fire the unit using either the remote cable or time delay button.

Golden Engineering has sold the x-ray device for packages in law enforcement applications, but sees other uses for it by electric utilities, oil producers, and heavy industries. The cost ranges from $3,000 to $5,000 per unit. This device was initially developed with BMDO funding at Los Alamos National Laboratory, where it served as an NDE technique for testing components in the SAWAFE program.

■ Idaho National Engineering Laboratory

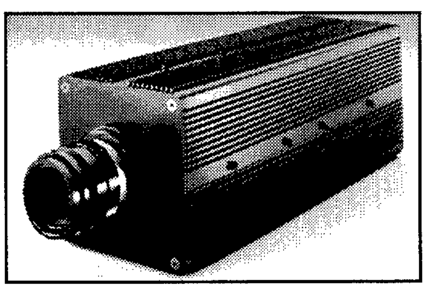
Idaho National Engineering Laboratory (INEL; Idaho Falls, ID) researchers have refined a technique called diffraction moiré interferometry that can nondestructively evaluate power plant components. Receiving early funding from the BMDO Innovative Science and Technology program, INEL has built several models of the interferometers, ranging from a small hand-held device that can be used in the field to a larger but higher performance dynamic testing model that incorporates an ultra-high-speed camera. The first INEL moiré system won a 1990 R&D 100 Award from *R&D Magazine* as one of the best industrial products of the year.

INEL's low-power devices function using two laser beams, directed toward a diffraction grating bonded to, or etched into, a material surface. When the beams diffract from the grating, they produce an interference pattern. Because the grating is attached to the surface, it distorts as the material distorts. This distortion changes the interference pattern produced by the grating. By analyzing these changes, material distortions can be measured.

Diffraction moiré interferometry can measure material distortions, or strains, as small as 20 nanometers. It has several advantages over other strain measurement techniques such as strain gauges, used in material analysis. First, it can detect strains over several square centimeters of a material. In contrast, strain gauges can only detect strains at a single point. Second, diffraction moiré interferometry is sensitive only to in-plane displacements. Other methods are often sensitive to in-plane and out-of-plane displacements; it can be difficult to separate the two types of displacement data, leading to confusion in interpretation. Finally, use of the diffraction grating that is attached to the piece or point to be measured greatly simplifies alignment and provides an absolute reference system for deformation measurements. Other interferometric techniques typically lack such a reference. Other funding for this research came from the U.S. Department of Energy, the U.S. Army, the U.S. Navy, and the U.S. Bureau of Mines.

■ Sensors Unlimited, Inc.

Sensors Unlimited, Inc. (Princeton, NJ), has developed and is selling an uncooled portable version of a near-infrared camera, which may be suitable for thermography applications. Among its numerous applications in the electric utility industry, it can detect heat buildup in power generation plant components, such as motors. It also can detect excessive heat buildup in transmission and distribution systems.



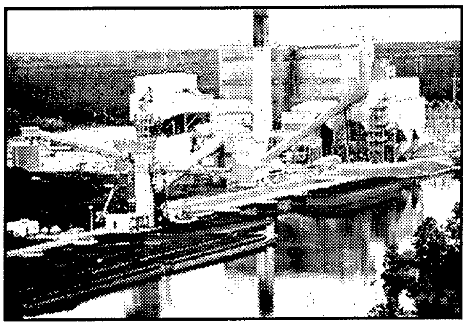
No cryocooler required: *Sensors Unlimited's uncooled infrared sensor is ideal for thermography applications because it can detect heat buildup on power generation plant components.*

Based on a design concept from a BMDO SBIR contract, Sensors Unlimited has eliminated the camera's cooling requirements, reducing the size and weight and making it about four times cheaper than uncooled infrared imagers used in the Persian Gulf War; Sensors Unlimited's camera costs about $25,000. The company has sold several of its uncooled near-infrared cameras for a wide spectrum of commercial uses such as to detect heat buildup in manufacturing processes. It also received a 1995 Commercial Technology Achievement Award sponsored by *Laser Focus World* and new product awards from *Photonics Spectra* and *Lasers and Optronics* magazines for the camera.

Sensors Unlimited's camera can provide on-board analog-to-digital conversion and digital output. Digital information can easily be sent to computer stations with minimal absorption or loss when transmitting information in the 1.55 micrometer range, which is the typical wavelength for fiber optics. Up to 512 frames can be stored in memory on the in-camera circuit board for subsequent display or storage. Sensors Unlimited's camera has a 128×128 pixel resolution. The company plans to upgrade the system's resolution to 320×240 pixels so that applications can be improved and expanded.

Employing Advanced Sensors

While the average power plant employs over 5,000 sensors for detecting various conditions, much of this technology has remained the same for nearly 20 years. Older sensors, with their more limited precision, do not allow control systems to yield optimum efficiencies. In addition, many of these devices cannot detect the subtle temperature, vibration, and pressure changes that may lead to serious problems in plant operations downstream.



Sensing changes: *Power plants can benefit from advanced sensors to detect subtle changes in power plant operations that may lead to serious problems downstream.*

For example, power plant operators have long strived to optimize the operating temperatures of the fossil fuel power plants and maintain these temperatures at a constant state. Higher temperatures can increase the energy efficiency of the plant. However, plant operators are limited as to how much control they have over plant temperatures, in part, because the reliability of standard detectors is not high enough, due to sensor drift, for engineers to implement precision temperature control. Therefore, lack of advanced temperature sensors limits power plant operators in obtaining optimum temperature capabilities.

Funding Technology Innovations

BMDO has funded significant research in small, accurate, and rugged sensors, essential for detecting and tracking ballistic missiles. Some research shows great promise for power plant operators as they seek ways to improve system performance. In one example of this technology transfer, researchers developed a BMDO-funded technology called the Johnson noise thermometer (JNT) to measure the temperature of the nuclear reactor coolant for the Space Nuclear Reactor Technology (SP-100) Program. Transferred from the satellite power project jointly funded by BMDO, NASA, and the U.S. Department of Energy, the JNT is now being applied to fossil fuel power generation to ensure accurate temperature measurements.

In addition, BMDO funded much sensor research and development to detect vibrations in space-based weapon systems. An example of such technology is a fiber-optic, light-emitting diode, which, when used in the utility industry, can help detect abnormal motor bearing vibrations that may indicate impending bearing failure. BMDO has also developed silicon-on-insulator technology for high-temperature pressure sensors in space and strategic defense applications. These sensors, now available as commercial products, could monitor performance of fossil-fuel power generation components.

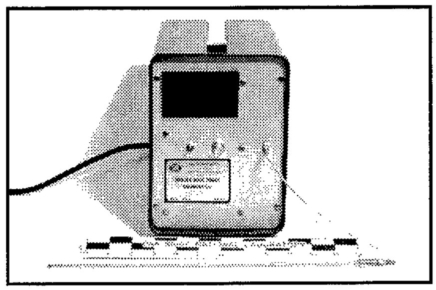
Moving the Technology to Market

■ Oak Ridge National Laboratory

Oak Ridge National Laboratory's (ORNL; Oak Ridge, TN) BMDO-funded development of the Johnson noise thermometer has led to a tool that can measure power plant combustion temperatures up to 1,100°C with a variance of less than 1 percent. This electronic

thermal sensor performs better than conventional resistance temperature detectors (RTDs), standard thermocouples, or optical pyrometers because it remains stable for long periods of time, eliminating the costly need to recalibrate or replace conventional thermometers. The JNT can predict the impending burnout of boiler tubes. In addition, its accuracies also help plant engineers know when and how much engineers should change the temperature to optimize operational temperatures so that power plants can generate power more cost-effectively.

As part of an EPRI-funded study, researchers at ORNL and the University of Tennessee (Knoxville, TN) developed several JNT prototypes. Engineers field-tested these devices at Tennessee Valley Authority's Kingston steam plant. In the tests, the devices operated as expected and verified all of the older sensor's temperature drift, which often occurs at such high temperatures. EPRI is negotiating the commercialization of JNT technology and will also address issues such as shielding materials and packaging requirements. It has already found one utility to support the research of these issues, and is looking for others.

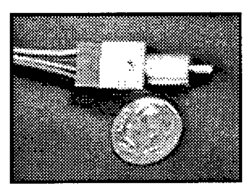


***Measuring temperatures up to 1,100°C:** The Johnson noise thermometer is being field-tested at the Tennessee Valley Authority's Kingston steam plant. It is designed to predict the impending burnout of boiler tubes.*

ORNL's JNT is a wire coil; four leads connect it to a signal processor. The device measures the alternating current (ac) noise and resistance, yielding the temperature by a simple calculation. Since the monitored signals are extremely small (microvolts), engineers have rigorously shielded the sensor and electronics to protect them from electromagnetic interference (EMF), which can degrade performance.

■ ERG Systems, Inc.

ERG Systems, Inc. (St. James, NY), designed, built, and tested a fiber-optic, light-emitting diode (FO/LED) sensor that can measure vibration and displacement of turbine generators in power plants. The FO/LED operates in a sealed monolithic housing attached to a dual fiber-optic probe. It is less than 3 cm long and less than 2 cm^2 in height and width. Because its sealed construction is rugged, it can perform in harsh environments. ERG Systems projects the sensor will cost about $40 when manufactured in volume.



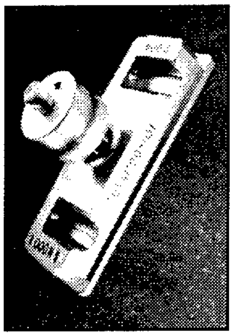
***Low-cost vibration sensor:** Projected to cost $40 when mass produced, ERG Systems' vibration sensor can measure vibration and displacement of turbine generators in power plants.*

The LED fiber-optic channel produces a constant light output reflected from the external (vibrating) surface into a photodiode input channel. The amount of light received at the photodiode depends on the relative displacement of the external surface. The device detects vibration by sensing oscillation of the photodiode's output signal voltage.

ERG Systems originally conducted this research to develop low-cost sensors for BMDO space-based systems, using SBIR funding. The company works with the Long Island Research Institute (Nesconset, NY), an organization that builds companies around new technologies. ERG Systems is ready to market its vibration sensor, and requires only customer specifications for implementation.

■ Honeywell, Inc.

Honeywell, Inc. (Plymouth, MN), developed radiation-hardened pressure sensors that, because they can withstand high temperatures, may find use in fossil-fuel power generation. Honeywell's line of devices, HOTronics™, features several pressure-measuring sensors that withstand high temperatures. These sensors can also measure magnetic fields.



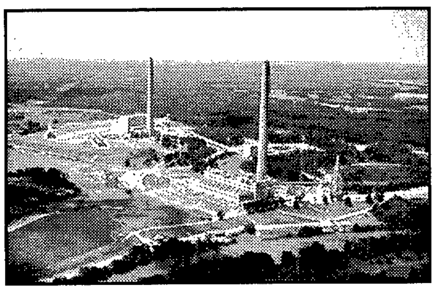
Taking the pressure: *Honeywell's HOTronics devices are pressure sensors that can operate reliably at high temperatures. They also can measure magnetic fields.*

Honeywell has delivered HOTronics™ devices to other industries with needs similar to those of the electric utility industry. One customer is an oil field instrumentation supplier that is testing the electronics for well measurement applications. Another customer is an aircraft engine manufacturer that will demonstrate the sensor while developing next-generation controls systems for commercial and military turbine engines.

Most electronics and sensors cannot operate reliably at temperatures higher than 125°C. However, Honeywell's Solid State Electronics Center (SSEC) has made high-temperature devices using silicon-on-insulator complementary metal-oxide-semiconductor (SOI CMOS) technology, initially funded by BMDO. SOI CMOS enables electronics and sensors to maintain performance and reliability at temperatures up to 225°C. Honeywell states that its approach of SOI CMOS presents the most practical and cost-effective way to achieve reliable operations at elevated temperatures. The company has tested the new high-temperature electronics and sensors in environments up to 300°C.

Monitoring and Controlling Plant Processes

As previously discussed, electric utilities are less inclined to retire old power plants and start new construction, but rather prefer to extend the life of existing plants through upgrades and modifications. Their approach leads to many challenges. For example, since power plant components are older, they are more vulnerable to failures from thermal stress. In addition, older plants lack the efficiencies of new power plants often due to the absence of new and more advanced instrumentation.



Visualizing the processes: *Fossil fuel power plants can benefit from distributed control systems, which can extend the life of power plants through higher efficiencies and lower thermal stress. These computerized systems allow technicians to know the status of power plant and control plant processes in real time.*

Therefore, to upgrade older plants, many managers have investigated the use of advanced computer-based distributed control systems (DCSs) as a way to optimize plant performance. These software-based computerized systems distribute control tasks among many computers, which are integrated into one system. Such systems can help plant operators visualize the status of system processes and then control those processes in real time. By employing such systems, the life of the plant can be extended through higher efficiencies and lower thermal stress.

In some cases, plant managers have also looked at similar software to simulate the monitor and control aspects of power plants so that new employees can learn how to deal with rare but critical instances of plant component or process failures by practicing necessary actions many times over. Engineers can also learn in weeks rather than years about all the aspects of, for example, powering up and down a plant and handling variations in heat or pressure to maximize efficiencies. Simulation software can also be used as a cross check for computer bugs and malfunctions than can sometimes occur when a new DCS is first installed in a power plant.

In the mid-1980s, the cost of DCS and simulation systems was prohibitive for utilities. For example, a full scope simulator could cost several million dollars, due to the high cost of hardware, software, and advanced instrumentation.[5] However, recently, new low-cost software and the decreasing cost of microprocessors are making DCS more feasible for electric utilities.

Funding Technology Innovations

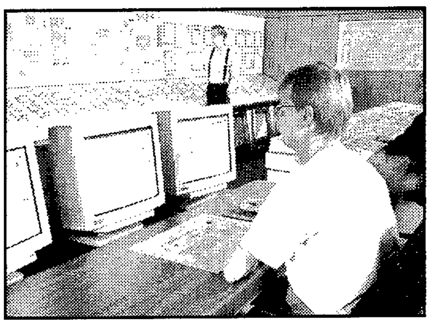
Originally developed at Los Alamos National Laboratory (LANL) and Argonne National Laboratory (ANL) to guide particle beams for accelerators, BMDO-funded software can be modified for use as DCSs to monitor and control fossil fuel power plants. The relatively low-cost, commercially available software package can also function as training simulators as described above. Developed in 1988, the software was part of a telescope-based system that controlled a low-divergence, 50 million electron volt (MeV) negative hydrogen ion beam. The telescope was constructed by LANL researchers and installed at ANL.

[5]Hoffman, S. 1995. A new era for fossil power plant simulators. *EPRI Journal*. September/October, p. 20.

Moving the Technology to Market

■ Vista Control Systems, Inc.

Vista Control Systems, Inc. (Los Alamos, NM), has applied the BMDO-funded automation and control software-based system from the telescope project to their simulation and monitoring applications. The company has sold over 30 software packages, called Vsystem®, both in the United States and throughout Western Europe. Software packages start at $9,000.



A classroom setting: Power plant students learn on a computerized simulator at the Kraftwerkschule in Dusseldorf, Germany. Providing the look and feel of a fossil fuel generating station, software simulates various problems encountered in a power plant setting and responds to students' decisions.

With this software, object-oriented graphics of system components (such as a valve) are linked to a parameter (such as pressure), presenting real-time visualization and control of the process. This software works in an open system architecture and provides a database, a graphical operator interface, an alarm system, a historical trending capability, and a function for controlling processes and equipment.

In one application, Vista Control's systems are serving in the Kraftwerkschule in Dusseldorf, Germany, as a training simulator for students from the electric utility industry. As an emulator, the software provides the look and feel of a fossil fuel generating station. It is installed in a control room that has the actual control panels and other features of a power plant. The software allows students to experience powering up and down the plant. It also simulates various problems and responds to students' decisions. In addition, it can emulate different types of software packages (such as for databases and report generation) that are used in the various power plants. In another application, Vista Control has sold the software to monitor working nuclear power plants in Germany and the United Kingdom.

Vsystem is designed for single or networked computers and workstations. Databases can run alone or in a distributed environment, and single or multiple input/output (I/O) subsystems may be used. Vsystem can be operated from OpenVMS™, ELN™, and UNIX® platforms. A Vsystem toolkit includes (1) a real-time database and library of access routines that maintain all information about the state and control of a project; (2) an active connection between the I/O hardware and the database; (3) a tool to design data acquisition and control screens that automatically connect to the database; and (4) a tool that logs data from the Vsystem database and produces a standard output file. It also conducts what-if studies by letting users play back all, or part, of a log file that is stored in a real-time database, a history and trending application for viewing logged data, and an interactive alarm module that can display and record alarm messages.

Predicting Plant Response for Higher Efficiencies

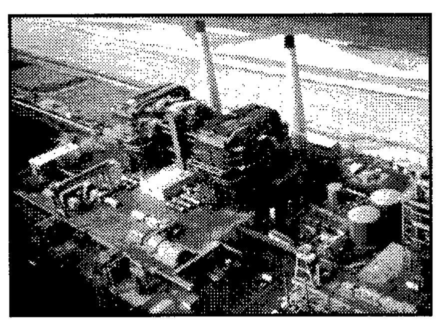
Because they inherently lack energy storage capabilities, fossil fuel power plants must produce electricity at the time of customer demand, and therefore are subject to load fluctuations. Such fluctuations, while inevitable, present challenges to power plant managers, as power plants are brought online and then back down to match load demands. Significant changes in power load can cause inefficient consumption of fuel, higher emissions from smokestacks, and thermal stress on power plant equipment. In addition, bringing power plants up and down is time consuming and expensive.

Able to address these concerns, predictive computational technologies, such as neural networks and algorithms, have sparked the interest of some plant managers. Derived from models of biological neural systems, neural networks are massively parallel processing systems that learn. These systems can predict various plant components' responses to factors such as fluctuation in power load. In doing so, the systems can improve or optimize a power plant's response to changing power conditions. Such rapid control over a wide range of operating conditions increases energy efficiency, enables faster load changes, and decreases thermal stress on equipment. In addition, the technologies may serve as predictive maintenance tools, able to diagnose process problems early on. Predictive computational technologies could save hundreds of thousands, even millions, of dollars for a utility in a year. They also could increase power reliability and quality, translating to better customer relations.

Funding Technology Innovations

BMDO has funded significant work in artificial intelligence (AI) such as algorithms and neural networks developed to help guide satellites and track a large number of incoming ballistic missiles. With modifications, these technologies may also address electric utilities' needs for predictive computational technologies, as described above. For example, BMDO funded work in algorithms that increase the processing speed of information after sensors collect the information when tracking ballistic missiles. Some of this technology has been incorporated into a system that can predict the power plant performance as highlighted below.

Predicting power plant response: *As simulated on Southern California Edison's El Segundo units, pictured below, Coleman Research Corporation's technology changed power output six times faster than current technology and produced higher fuel and performance efficiencies.*



Moving the Technology to Market

■ Coleman Research Corporation

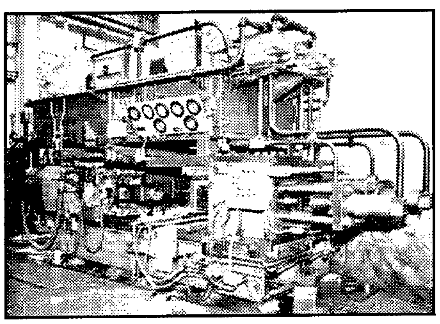
Coleman Research Corporation (CRC; Columbia, MD), through BMDO SBIR funding, has developed an algorithm called the decentralized square root information filter (SRIF) that lowers the processing demands of predictive control systems. The SRIF optimizes computer and sensor resources by combining redundant data and reducing the number of calculations that a processing system must handle. CRC has incorporated SRIF technology into data fusion modeling (DFM), a predictive modeling tool for decision makers. This software combines a priori knowledge—such as physical and statistical processes—with data from sensors.

CRC, with assistance from the National Science Foundation (NSF), has applied aspects of SRIF technology to fossil fuel power plants for nonlinear model predictive control (NMPC)—a system that predicts the plant response to control actuators. Among its many benefits, NMPC enables faster load changes with tight control of steam temperatures, improves plant efficiency for fuel and cost savings, and leads to longer equipment life by lowering thermal stress. CRC developed NMPC under two SBIR grants from NSF, using some of the lessons learned through the BMDO SBIR contract. In a simulation, NMPC was later applied to two 340-megawatt, gas-fired drum units at Southern California Edison's El Segundo Power Plant. The system changed the power output of the simulated plant about six times faster than by conventional means, and produced higher fuel and performance efficiencies, translating to hundreds of thousands of dollars in savings potential.

Also, CRC's DFM has been fully developed to provide two- and three-dimensional predictive modeling for environmental risk assessment at power plant sites (as well as others). The software, which predicts the movement of groundwater contaminants, should be available for high-end personal computers in the near future.

■ NETROLOGIC

NETROLOGIC (San Diego, CA) has developed neural networks and genetic algorithms that may be applied to model power plants, predict their behavior, and then control their processes in real time. The technologies can also be used to detect system defects and diagnose problems or faults before power plant performance is impaired. This work was initially conducted through a BMDO SBIR design concept.



Detecting process defects: *The National Center for Manufacturing Sciences worked with NETROLOGIC to develop a way to detect machine defects in industrial presses, such as the one pictured above. The company's developments could be used to perform similar functions in power plant processes.*

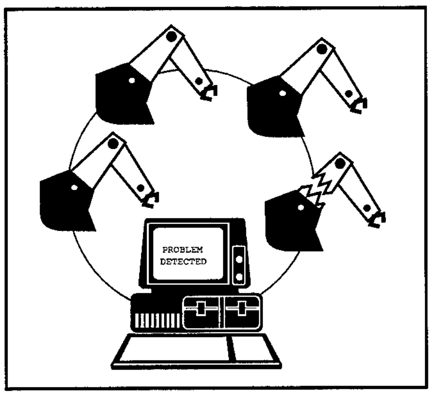
NETROLOGIC has already worked in the industrial process area with General Motors (GM) and the National Center for Manufacturing Sciences (NCMS) to use wavelet signal processing and neural networks for monitoring industrial processes. In the NCMS project, NETROLOGIC's wavelet signal processing algorithms helped isolate short-lived signals (such as an anomalous vibration) for detecting machining defects. These wavelets are "time signatures" that occur in a nonsteady state or nonstationary manner. With these powerful methods, problems too complex to be solved using conventional analysis are solved by treating large numbers of variables in a random and iterative fashion.

In general, NETROLOGIC's genetic algorithms and neural processing allow system operators or plant engineers to select sets of input and output variables that characterize the state of a complex system. After processing information about the system's initial state, the plant generates a new set of variables that can be used as input for a new iteration. This process is repeated until a target set of variables is reached, and the system is said to have "learned" the correspondence between plant input and output variables. NETROLOGIC has continued this, and related, research in tandem with the U.S. Department of Education, the U.S. Navy, the U.S. Air Force, NASA, the Defense Advanced Research Projects Agency, and NCMS, among others.

On a futuristic note, the company is also part of the Lunar Power System Coalition, which advocates the development of a lunar-based solar collection system. In the proposed system, solar energy would be converted to microwaves and transmitted to earth as a global-scale source of clean electrical energy.

■ Intelligent Automation, Inc.

Intelligent Automation, Inc. (IAI; Rockville, MD), is developing artificial intelligence called autonomous agents, which the utility industry could use to optimize the performance of power plants. IAI is addressing limitations associated with present-day industrial control systems, which have been designed to handle predetermined situations but are paralyzed when confronted by an unplanned event. This limitation makes design of centralized systems difficult since every situation must be explicitly handled. Another problem with centralized systems is that the data used for decision making may be delayed and not completely accurate. The behavior of even relatively simple systems can become chaotic in the presence of these factors.

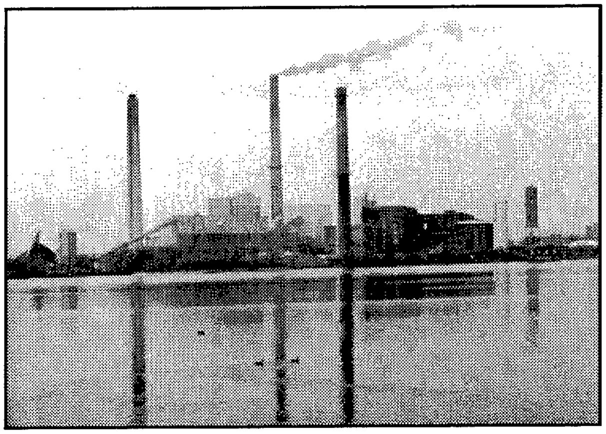


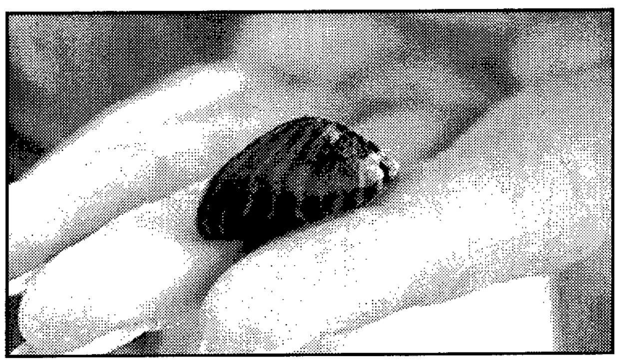
Controlling chaotic systems: *IAI's technology quickly reacts to unforeseen events by permitting moment-to-moment intelligent decision making at the equipment level.*

IAI's autonomous agents control the behavior of complex and deterministically chaotic systems. The self-contained units negotiate with each other to rapidly arrive at correct decisions. This distributed approach to optimization is much faster and more robust than centralized systems, where directions are issued from a centralized source. And, according to IAI, autonomous agent technology is easier to implement than software that performs mathematical global analysis for optimization of system performance. In a major manufacturing facility, the existing software was replaced by autonomous agent technology. The number of system failures decreased from several a day to almost none and performance was superior to previous experience.

The overall behavior of a complex system that emerges under the control of autonomous agents is not well understood, but initial experiments show behavior is near optimal, stable, and robust to changes. BMDO SBIR funding is helping IAI study how autonomous agents behave and interact to improve overall system operation. The specific context for BMDO is battle management, but the technology is very general and can be applied to many decision-making problems.

IAI is also receiving support from the Defense Advanced Research Projects Agency to apply this technology to factory scheduling. Flavors Technology, Inc. (Manchester, NH), is supplying private funds for this application.





▲ Top: ***Not just blowing smoke:*** *In 1994, fossil-fuel steam-electric generating units released over 13.1 million short tons of sulfur dioxide (see page 41). Advanced technology can help utilities in their plight to reduce and monitor these emissions.*

▲ Bottom: ***Menacing mollusks:*** *Biofouling remains a concern for power producers, sometimes costing millions of dollars in removal or damage. Zebra mussels, pictured above, are one example (see page 48).*

All electric utilities impact the environment in some way. They may emit sulfur dioxide (SO_2), which causes acid rain; they may release large amounts of greenhouse gases such as carbon dioxide (CO_2); or, they may impact water resources and land use because of activities related to biofouling or spent fuel. In 1994, fossil-fuel steam-electric generating units released over 13.1 million short tons of SO_2 and over 1.9 billion short tons of CO_2.[1] In addition, the Nation's light-water reactors discharged over 30,000 metric tons of uranium.[2]

The Federal and state governments heavily regulate the electric utilities' impacts on the environment. On the Federal level alone, more than 15 pieces of major legislation relating to environmental issues affect power producers; examples include the Clean Air Act of 1963, which affects power producers through, among other rules, the Acid Rain program. The Clean Water Act of 1977, in establishing a system for setting national effluent standards for pollutant discharges, largely impacts power plant operations using large amounts of water for steam or cooling. And the Energy Policy Act of 1992 includes, among other items, various provisions regarding global warming and the release of greenhouse gases.

Therefore, electric utilities spend a significant amount of their budget on environmental technologies. For perspective, in 1994, average costs for the operation and maintenance (O&M) of flue gas desulfurization systems were about .0114 cents per kilowatt-hour.[3] This small fraction of a penny translates to hundreds of millions of dollars in O&M expenses that year for coal desulfurization alone on a national scale.

An electric utility's portfolio for addressing environmental impact might include a number of different strategies. For example, it might include avoidance technologies, which are alternative power producing strategies that do not pollute. It might also include control technologies that stop existing pollution at the source, preventing its release into the environment. Or it might include monitoring technologies to detect pollution levels or remediation technologies to treat pollution problems that have already occurred.

BMDO has funded sensor, materials, and power technologies that have environmental applications relevant to electric utilities. For example, BMDO funded sensor technology for numerous applications including tracking and detecting ballistic missiles. It funded advanced materials for superconductivity to provide highly efficient communications electronics with low power requirements for space applications. And it funded power technologies for applications such as eliminating ballistic missiles. These technologies can also address environmental monitoring, emissions control, biofouling, and waste treatment issues relevant to electric utilities.

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[1]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 45.

[2]Energy Information Administration. 1996. *Spent Nuclear Fuel Discharges from U.S. Reactors 1994.* p. xiii.

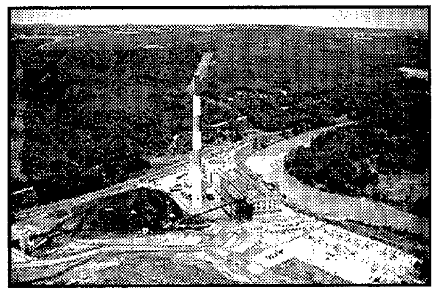
[3]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 50.

The following section highlights some of these technologies, to solve the following problems:

- Monitoring Emissions from Smokestacks
- Controlling Pollution in Smokestack Emissions
- Removing Zebra Mussels from Power Plant Components
- Producing Electricity with Environmentally Sustainable Technologies
- Reducing the Impact of Nuclear Waste

Monitoring Emissions from Smokestacks

In the 1960s, public outcry about the growing air pollution problems resounded throughout the halls of Congress and state agencies, resulting in Federal and state regulations to protect air quality. These regulations have affected electric utilities significantly because fossil fuel power plants are major sources of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions. For perspective, in 1994, electric utilities in the United States emitted 13.1 million short tons of SO_2 and 5.7 million short tons of NO_x.[4]



Monitoring requirements: *Power plants generating over 25 megawatts must use continuous emissions monitoring systems to sample, analyze, and record emissions data at least every 15 minutes.*

A major law that affects allowable emissions is the Clean Air Act of 1963, amended in 1967, 1970, 1977, and 1990. The Clean Air Act regulates the emission of several air polluting substances including particulates, SO_2, NO_x, carbon monoxide (CO), ozone, and lead. Even more significant is the corresponding Clean Air Act Amendment of 1990, which mandated the Acid Rain Program through the Environmental Protection Agency (EPA). This program has established monitoring requirements through the continuous emissions monitoring (CEM) rule, which requires power plants generating electricity over 25 megawatts to use CEM systems. Electric utilities must report each short ton of emissions of SO_2, NO_x, volumetric flow, diluent gas, and opacity of units (the percentage of light that one can see through the flue gas). According to requirements, CEM equipment must be able to sample, analyze, and record data coming from their discharge stacks at least every 15 minutes.[5]

In many cases, the CEM rule, as well as state-mandated programs have provided incentives for electric utilities to implement better emissions-monitoring equipment. In addition, utilities have been investigating equipment to detect soil contamination from leaky pipes, storage tanks, and other sources.

Funding Technology Innovations

BMDO-funded research and development in several areas has evolved into advanced equipment that can provide data in real time for environmental monitoring. For example, a company is transferring BMDO-funded work in Fourier transform infrared (FTIR) spectroscopy to industry for environmental stack monitoring applications. BMDO originally funded advanced FTIR technology to monitor the deposition of high-temperature superconducting materials used in ballistic missile defense.

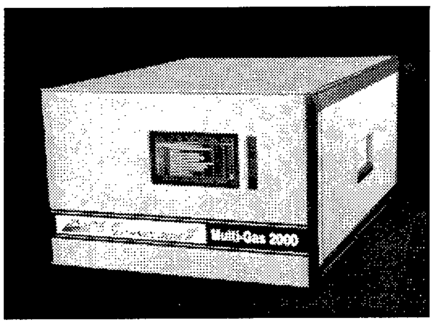
BMDO has also supported the development of a midwave IR focal plane array sensor for the Advanced Large-Area IR Transducer (ALIRT) Program. Researchers designed ALIRT to improve IR sensor technologies that could detect and track intercontinental missiles. They are now transferring this technology to industry for analyzing stack emissions from remote locations. For example, the technology could help verify compliance with environmental regulations.

[4]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 45.
[5]Environmental Protection Agency. 1996. CEM Factsheet. 26 October, p. 2. Internet. [http://www.epa.gov/acidrain/cems/].

Moving the Technology to Market

■ On-Line Technologies, Inc.

On-Line Technologies, Inc. (ONLINE; East Hartford, CT), is selling a continuous emissions monitoring system called the Multi-Gas Analyzer, which can be used for stack gas and ambient air monitoring. Based on FTIR spectroscopy, this device can simultaneously analyze up to 50 gases, such as CO, NO_2, and SO_2. It then can display 10 gas concentrations on a computer at the same time. FTIR spectroscopy uses an infrared beam to acquire emission, reflection, and transmission spectra of a substance. Users can obtain data simultaneously at all infrared wavelengths. To obtain the spectra, a computer processes this data in real time using a Fourier transform algorithm. These spectra reveal information about the substance's composition, temperature, concentration, and dimensions.



Monitoring in near real time: *ONLINE's Multi-Gas Analyzer, pictured above, is a continuous emissions monitor that can analyze up to 50 gases at the same time.*

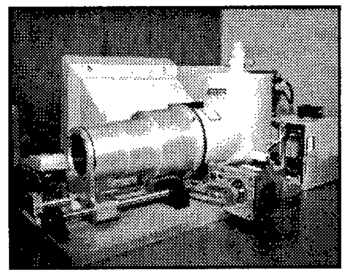
ONLINE's Multi-Gas Analyzer has a 10.0 parts-per-billion sensitivity with a five minute measurement time and a 0.2 parts-per-million sensitivity for most chemical species, in about one second. It also can automatically compensate for temperature and pressure. The company markets two versions: Model 2001, which sells for $49,950, includes a touch screen computer, while Model 2002, for $10,000 less, does not include a computer.

ONLINE serves as the manufacturing and commercial subsidiary of Advanced Fuel Research, Inc. (same location), and has applied FTIR research to the Multi-Gas Analyzer. Addressing needs similar to the electric utility industry, AFR is working with the Gas Research Institute to develop low-cost devices that monitor smokestack emissions for industrial-based gas customers in an $800,000 cost-shared contract. This research is a variation of the Multi-Gas Analyzer. BMDO funded FTIR technology to monitor the deposition of oxide materials for superconducting components.

■ Pacific Advanced Technology, Inc.

Pacific Advanced Technology, Inc. (PAT; Santa Ynez, CA), developed an imaging spectrometer called the "image multi-spectral sensor," which, when used with Amber Engineering's (Goleta, CA) Radiance 1 midwave infrared imaging camera, can remotely monitor stack emissions. In the highest data acquisition mode, spectral images over the 3 to 5 micron band with 200 spectral bins can be collected in less than one second. This product is now available. Demonstrated in the field, the device detected CO and CO_2 in stack emissions from an oil refinery that was 1 kilometer away. PAT believes the system can also identify sulfur dioxide and other gases in the 3- to 5-micron range and is interested in demonstrating these capabilities.

The Radiance 1 camera is a digital imaging system for infrared (IR) photography based, in part, on BMDO research programs for space-based IR surveillance sensors. Amber has taken a lead role in integrating indium antimonide (InSb) array sensors, advanced compact cryocoolers, and image control and processing software into systems that can be obtained commercially at costs comparable to other lower-performance systems. The heart of the digital IR camera is the InSb focal plane array sensor. The typical detector array size is now 256 x 256 pixel elements, but Amber is also producing arrays of 512 x 512 pixels.

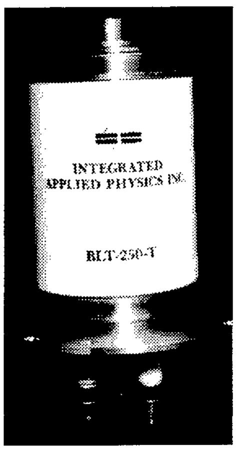


Monitoring from afar: *Pacific Advanced Technology's imaging spectrometer, when used with Amber's Radiance 1 camera, can remotely monitor smokestack emissions.*

Amber integrated detection and signal processing electronics (such as a fast digital frame grabber), digital signal processing algorithms (such as fast Fourier transform processing), and display software into easy-to-operate image acquisition and manipulation systems. The newest system operates on a Pentium™-based PC and takes advantage of the most recent fast video display bus architecture. BMDO originally funded the camera for the ALIRT program. PAT received funding for the image multi-spectral sensor through the BMDO SBIR and other DOD programs.

Controlling Pollution in Smokestack Emissions

As part of the Clean Air Act Amendment (CAAA) of 1990, legislation will require fossil fuel power plants to reduce sulfur dioxide (SO_2) emissions by 10 million tons and nitrogen oxide (NO_x) emissions by 2 million tons, as compared to 1980 levels. These reductions are occurring in two phases; one phase began in 1995 and another will begin in the year 2000. While certain allowance programs are being implemented to help power plants meet these standards, they will disappear by 2010. Therefore, many utilities will eventually be forced to decrease their emissions of SO_2 and NO_x.



***Pulse power innovations:** The backlighted thyratron is a BMDO-funded pulse-power switch that Integrated Applied Physics marketed, targeted as part of a system for emissions control.*

Coal burning power plants currently reduce emissions in several ways. Some go right to the source and burn low-sulfur coal, which is more prevalent in the western United States, but is also more expensive. They also use control technologies that capture and/or neutralize hazardous substances before these pollutants enter the environment.

While environmental control systems vary, fossil fuel power plants often use flue gas desulfurization systems, called scrubbers, to control the emissions of SO_2. In general, such systems allow combustion gases to pass through tanks containing a material that captures and neutralizes the SO_2. In 1994, the average scrubber system in the United States (latest data available at the time of this report) was roughly 80 percent efficient, but system efficiency varied drastically, ranging from just under 12 percent to 98 percent.[6] Scrubbers eventually produce pollution in the form of solid waste, which requires disposal. According to the Electric Power Research Institute, the U.S. electric utility industry spends over $1 billion each year to dispose of fly ash and scrubber sludge.[7]

Funding Technology Innovations

BMDO funded work in high-power thyratrons and power modulators to serve as switching devices for high-powered lasers and particle accelerators through both the Innovative Science and Technology (IS&T) research program and the Organization's SBIR program. BMDO initially pursued such a technology to help destroy enemy ballistic missiles. But developments have been incorporated into a pulsed power system that could help electric utilities meet compliance with regulations stemming from the CAAA of 1990 while also reducing waste disposal requirements.

Moving the Technology to Market

■ Integrated Applied Physics

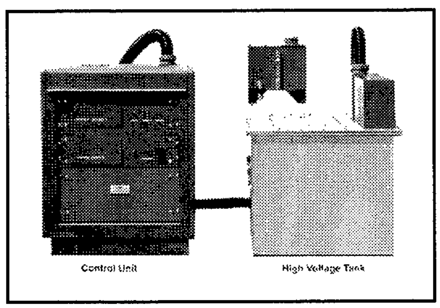
Integrated Applied Physics (Torrance, CA) has demonstrated a high-powered, extremely short-pulse modulator that power plants can retrofit into electrostatic precipitators to decompose pollutants from smokestack emissions such as SO_2, NO_x, and volatile organic

[6]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume I.* November, pp. 51–56.
[7]Electric Power Research Institute. 1996. *Pollution prevention and waste/water management: technologies and guidelines for environmental excellence.* 3 December, p. 2. Internet. [http://www.epri.com/cgi-bin/].

compounds. Electric utilities sometimes use electrostatic precipitators to remove particulates, but the technology currently does not remove gases. Integrated Applied Physics' technology can increase the performance of pollution control systems to over 99 percent while also eliminating scrubber sludge and significantly reducing fly ash.

This technology is based on the use of pulsed corona discharge (PCD). In PCD, a high-voltage, extremely short pulse is applied to form a discharge in a suitable electrode structure. During the formation of the discharge, a nonthermal plasma is produced. The plasma's high-energy electrons cause chemical reactions that either decompose the pollutants into nonhazardous products or convert them to particulates, which the adjoining electrostatic precipitators can remove.

Integrated Applied Physics' pulsed modulator solves problems encountered with PCD by properly tailoring the pulses to improve the energy efficiency of the process. PCD was previously demonstrated at an electric utility in Italy and successfully decomposed pollutants to minute levels; however, the modulator used did not have short pulse capabilities; therefore, the energy efficiency and reliability of the control system suffered. In these earlier systems, the discharge energy was wasted in heating the plasma ions, which do not participate in useful reactions. Short (less than 100 nanoseconds) pulse lengths and high energies (100 kilovolts [kV]) are required to increase the efficiency of this process. Also, short pulse rise times of less than 10 nanoseconds and the ability to deliver currents of between 1 and 20 kiloamperes [kA] are required. One experiment demonstrated that a device with such capabilities would increase energy efficiency by a factor of three.



Products on the market: *The BNE-50-2-4, pictured above, is one of the modular products that Integrated Applied Physics is selling for emissions control.*

Meeting these requirements, Integrated Applied Physics has developed an experimental prototype; engineers could assemble several prototypes in a series to demonstrate power-plant-level applications. Much of this development is based on research through the BMDO SBIR program, and through IS&T research at the University of Southern California. As a first step, the company is selling modular products such as the BNE-50-2-4 short pulse, high-voltage power supply that can deliver 50 kV pulses at 2 kA with a pulse width of 200 nanoseconds. This product can be used in small-scale environmental control applications. The company has delivered modulators with various output voltages, pulse repetition rates, pulse lengths and currents, including a modulator with output over 100 kV, and another with repetition rates up to 20,000 Hz. The technology is also being studied for compliance with engine emission requirements, and is currently under study by the U.S. Navy at Pt. Hueneme, California, for diesel emission control.

Removing Zebra Mussels from Power Plant Components

Zebra mussels have presented a major challenge for many electric utilities in the United States, acting as power plant parasites. These small shellfish recently infested many of the Nation's rivers and lakes, able to attach to almost any hard surface underwater. Highly prolific in nature, they often form extensive colonies inside power plant condensers and heat exchanger tubes in infested waterways, leading to decreased heat exchange efficiency. They also can inhabit and clog service lines that deliver water for cooling transformers and other critical components.

The zebra mussel has long been a problem in Europe, but is a newcomer to the United States, first found in 1988 in the Great Lakes region. It landed in this region because foreign ships carried the mussel larvae in ballast water. The hardy species has since invaded many of the Nation's waterways, sighted as far south as Baton Rouge and as far east as the Hudson River. Such rapid spread has sparked considerable concern on the part of utilities and other industries nationwide. Proliferation also presents other environmental problems, which extend beyond the scope of this report.

***Small species, big problems:** The zebra mussel, pictured above, in numbers, can colonize and clog service lines that deliver cooling water for transformers.*

Larvae of zebra mussels are very small, often rendering filtration ineffective. Once the larvae have penetrated an area, they proliferate, forming large colonies and growing to a much larger size. Therefore, many electric utilities with power plants positioned along waterways in infested regions have resorted to expensive control systems that, for example, treat the zebra mussels and their larvae with chlorine to eliminate them. In such cases, the treated water must then be dechlorinated to prevent damage to the river's ecosystem.

Utilities have pursued other approaches as well, which, in some instances, have presented labor, time, and safety issues. For example, in a case study involving mature zebra mussel populations, workers at an electric utility in the Great Lakes region dewatered an infested power plant structure and removed the zebra mussels with a high-powered spray. Because of the extensive amount of flying debris, the workers wore protective body wear. In addition, due to delays in debris removal, a foul odor quickly developed from the decay of the biomatter. More than just a bad smell, odor raises considerable concern because it can cause oxygen deprivation and expose workers to high levels of decomposition gases such as hydrogen sulfide.[8]

Funding Technology Innovations

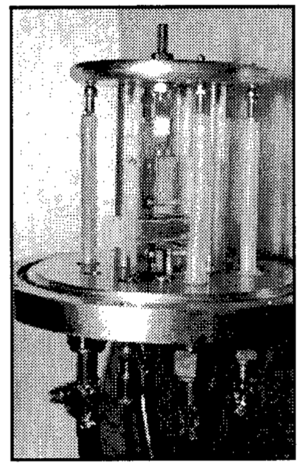
BMDO funded work in a semiconductor-based pulsed power device, called the pseudospark switch, that can produce ultrashort electrical pulses for space-based directed energy weapon systems. Researchers are transferring this technology to the environmental arena, developing a nonpolluting, less labor-intensive way to discourage zebra mussels from forming colonies on power plant components.

[8]The Zebra Mussel Information Clearinghouse. 1994. *Dreissena!* October/November/December (Volume 5, Issue 5), p. 3.

Moving the Technology to Market

▪ Old Dominion University

Researchers at Old Dominion University (ODU; Norfolk, VA) are using a BMDO-funded "pseudospark" switch developed at the University of Southern California to eliminate the growth of zebra mussels in water-based systems around power plants and other industrial facilities. Their technology acts as an electric fence, continuously applying ultrashort pulses of electricity. The pulses stun the mussels, continuously preventing them from clinging to the surface and then colonizing on pipes and other components.



Acting as an electric fence: *The pseudospark switch, pictured above, acts as an electric fence, continuously applying ultra-short pulses of electricity to a power plant's cooling system.*

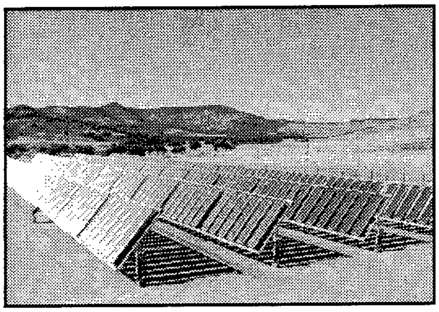
Field studies where tidal water was used to demonstrate the pulsed electric field effect were very successful. The system could completely suppress biofouling when the water was electrically treated. The treatment system's efficiency (the amount of water that could be treated with the energy of 1 kilowatthour [kWh]) exceeded 5,000 liters per kWh for tidal water. For fresh water, this efficiency can easily reach values of 100,000 liters per kWh. In a related project, ODU has been participating in a consortium to develop this technology for eliminating zebra mussels from the ballast water of ships as part of a $2-million project for the Defense Advanced Research Projects Agency. The consortium includes ODU, the South Tidewater Association of Ship Repairers, the Commonwealth of Virginia, and the City of Norfolk.

The pseudospark switch can produce ultrashort electrical pulses of 1 million watts or more. It is made of silicon-doped gallium arsenide (GaAs:Si), which is counter-doped with copper atoms to produce a semi-insulating material of GaAs:Si:Cu. The switch is activated by a neodymium YAG laser, which energizes electrons that the copper impurities trap. The electrons remain in this energy state for several microseconds, and, as long as they are trapped, current flows through the switch. A second laser turns off the current. Optical control of the switch allows researchers to vary the pulse duration with extremely high accuracy.

The pulse duration can be as short as 100 picoseconds, making it the fastest known high-power switch that can be gated. By providing switching speeds this fast, as applied to remove zebra mussels, the system can deliver short bursts of intense electrical power without depositing significant amounts of heat. Short electrical pulses can also be used to affect the ion exchange in cells without heating the cell, making the technology useful in applications such as cold debacterialization (removal of bacteria) of fluids.

Producing Electricity with Environmentally Sustainable Technologies

As previously described, the emissions of particulates and gases such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and carbon dioxide (CO_2) are controlled by Federal and State government regulations because of their adverse effects on environmental conditions. Such effects include, but are not limited to, acid rain and global warming. An initiative called the Climate Change Action Plan, which began in 1993, encourages the reduction of greenhouse gases, such as CO_2 and nitrous oxide to 1990 levels by the year 2000. Improvements such as increased heat rates in fossil fuel burning power plants can markedly reduce the release of air pollutants; however, at least one source projects that such measures will not be enough to meet the outlined goals. According to Tony Armor, director of Fossil Power Plants at the Electric Power Research Institute, "Although high-efficiency fossil plants can make an important contribution to the global climate issue, more dramatic changes in energy production will likely be needed to reverse increasing CO_2 levels. These changes could include more rapid introduction of fuel cells and the introduction of renewables, particularly photovoltaics (PV), on a large scale."[9]



Emission-free power generation: *Solar arrays, such as ones using ENTECH's line-focus Fresnel lenses, can be used to provide utility-scale power generation. Because they do not emit pollutants such as sulfur dioxide and nitrogen oxides, they can provide many environmental advantages.*

Technologies such as photovoltaics, solar thermal systems, and fuel cells produce electricity without emitting particulates and pollutant gases into the atmosphere. (In the case of fuel cells, emissions exist but are negligible.) PV technologies are optoelectronic devices or "cells" that convert solar energy to electricity; solar thermal systems collect solar heat and convert it to electricity; and fuel cells combine hydrogen and oxygen in an electrochemical reaction to generate electricity. These "avoidance" technologies can reduce the need for pollution control strategies that electric utilities must undertake to comply with Federal and State regulations. Utilities have investigated the use of solar and fuel cell technologies for years, and some are using such technologies on a limited basis. For perspective, in the Nation, photovoltaic systems provided about 12 megawatts (MW) of central station power capacity in 1995, and solar thermal systems provided about 330 MW of central station power capacity in 1993.[10] Experts project that electric utilities in the United States will have about 810 MW of central station grid-connected PV and solar thermal generating capacity by 2010. This projected capacity could provide enough electricity to power over 240,000 homes.[11]

In addition, such technologies have an even bigger impact abroad, where the power grid may supply electricity only during certain hours or where it is nonexistent due to the lack of industrialization. In fact, solar and other alternative technologies may be the first

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[9]Armor, T. 1996. From the Director, Fossil Plant Efficiency, Carbon Dioxide, and Global Warming. Internet. [http://www.epri.com/or/gg/fospp/news/fall05/warming.html].
[10]Energy Information Administration. 1995. *Annual Energy Outlook*. January, p. 33.
[11]Energy Information Administration. 1996. Telephone interview by Leslie Aitcheson. October 17.

electricity sources that rural communities experience.[12] In such instances, nonpolluting technologies become all the more important as these areas experience more industrialization and begin to increase present pollution levels on a global scale.

Despite the benefits of advanced environmentally sustainable systems, cost, efficiency, and site requirements have limited their prevalence. Technological advances are addressing these issues.

Funding Technology Innovations

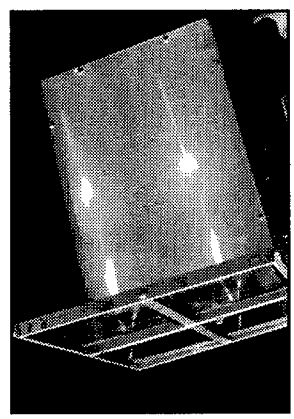
BMDO has funded several technologies that utilities are using, or are expected to use, for central station power. For example, BMDO is developing photovoltaics to provide power for satellites and other space-based vehicles. Such technologies include solar concentrators that increase the efficiency of the solar cells, as well as the solar cells themselves. When used for terrestrial applications, these technologies improve the efficiency of solar energy systems while also providing cost benefits.

Through its SBIR program, BMDO has also funded work in heat pipes for numerous space-based and terrestrial applications to cool electronic and microelectronic ballistic missile defense components. Developers have transferred this technology to the solar energy industry to cool utility-level solar thermal systems. In addition, BMDO has also funded research on fuel cells as a power source for space-based missions. The utility industry can also use fuel cells as a cleaner source for energy generation.

Moving the Technology to Market

■ Northeast Photosciences, Inc.

Northeast Photosciences, Inc. (Hollis, NH), has developed a holographic device that greatly improves the efficiency of solar energy conversion of photovoltaics; the device has net conversion efficiencies of over 30 percent. This technology is being commercialized by the HOLOS Corporation (Fitzwilliam, NH). Northeast Photosciences conducted a cost analysis for power generation that showed that the holographic device can compete with nuclear and fossil fuels when accounting for environmental externality (clean-up) costs. The cost analysis of the device indicated that these holograms allow solar cells to produce electricity for just 5 to 6 cents per kilowatthour (kWh).



Ultra-high efficiencies: *Northeast Photosciences' holographic device has net conversion efficiencies exceeding 30 percent. Arizona Public Service has agreed to host a test site for this technology.*

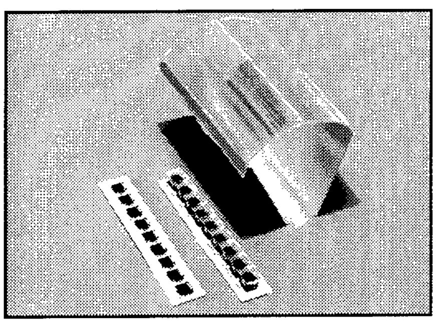
Arizona Public Service utility has agreed to host a test site for a massive hologram to generate utility-scale power. Northeast Photosciences has also discussed commercialization with a venture capital investor interested in improving the performance of solar cells, and with the Naval Air Warfare Center in China Lake, California, for using the hologram in SELENE, a program to beam power to a satellite solar power system using a free-electron laser.

[12] Moore, T. 1995. Developing countries on a power drive. *EPRI Journal*. July/August, p. 8.

The holographic solar-cell technology consists of a single-element hologram, which spectrally separates light and focuses it perpendicularly to the cell surface in a thin concentrated line. By spectrally separating the light, the hologram lets two or more different solar cells absorb only those wavelengths each cell most efficiently converts to electrical power. The system diffracts only the effective radiation to the solar cell, while the undesired infrared radiation totally bypasses the cells; this feature reduces cooling requirements. In addition, the technology's side-by-side design (or side focus) replaces the difficult-to-cool stacked design and improves solar-cell efficiency by eliminating shadow effects. BMDO originally funded this research through its SBIR program to increase the efficiency of space-based solar power generation.

■ ENTECH, Inc.

ENTECH, Inc. (Keller, TX), manufactures a type of solar concentrator called the line-focus Fresnel lens that increases the efficiency of PV modules. ENTECH replaces expensive PV cells with a relatively low-cost lens and heat dispersion material.



High tech translating to lower costs: *ENTECH's arched lens can direct sunlight onto a narrow strip of photovoltaic devices, directing about 90 percent of the incident light onto the solar cells and replacing expensive photovoltaic cells with relatively low-cost materials.*

The patented design uses an arched lens that focuses sunlight onto a narrow strip covered with photovoltaic devices. The lens can direct about 90 percent of the incident light to the solar cells, reducing the need for stringent lens manufacturing and installation tolerances. The optical efficiency also permits the solar array to have one degree of sun tracking error without a loss of usable solar energy.

ENTECH has incorporated some of the research from space-based projects into a utility-scale product called SolarRows to achieve more efficient solar energy conversion. A SolarRow consists of 72 Fresnel lens modules, each 3 x 12 feet, attached to a computer-controlled, sun tracking structure 341 feet long. ENTECH can assemble many 25 kilowatt (kW)-producing SolarRows together to produce large power plant capacities.

In March 1995, the Texas Utilities Electric Company dedicated a 100-kW power plant at the utility's renewable energy demonstration and test facility. In September 1995, Central and South West Corporation (CSW) dedicated a 100-kW power plant at CSW Solar Park near Fort Davis, Texas. Both power plants include four SolarRows as the photovoltaic collector field.

In addition, ENTECH, in participation with a team headed by Nevada Power Corporation, was selected in February 1996 as one of the firms to provide large-scale solar power plants for the Solar Enterprise Zone (SEZ) in Nevada. The SEZ project is a Federal, state, and industrial partnership, which could result in 20 MW capacity of ENTECH equipment installed and operational in the Nevada desert by the year 2000.

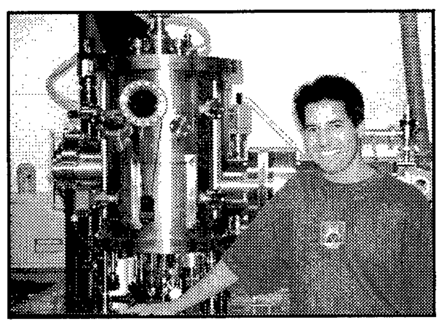
Earlier systems have been installed at the U.S. Department of Energy's (DOE's) Sandia National Laboratories, Pacific Gas & Electric, and the Tennessee Valley Authority. ENTECH also has participated with DOE under its Photovoltaic Manufacturing Technology

program, a program in which solar industry companies teamed with the Federal government to identify and develop solutions for manufacturing problems.

For small or remote site electrical demands, ENTECH also markets a SUNLINE™ stand-alone power unit. In this system, a platform holds two cylindrical solar collectors that track the sun in two axes, producing 1,000 watts at peak output. BMDO funded work on the line-focus Fresnel lens through its SBIR program for improved power generation in space-based missions.

▪ University of Texas

University of Texas at El Paso (UTEP; El Paso, TX) researchers are using new materials to improve characteristics of photovoltaic systems. Traditionally, users of photovoltaics could choose from two basic material approaches—crystalline silicon and amorphous silicon—both with different advantages and disadvantages. Commercial crystalline silicon solar cells have conversion efficiencies of roughly 15 percent, but the crystalline's greater thickness leads to higher costs, which range from \$3.50 to \$4.00 per generated watt (W). Amorphous silicon solar cells, a thin-film alternative, have lower costs; however, they have corresponding lower conversion efficiencies, ranging from 4 to 6 percent for commercial single-layer cells and tend to degrade at a high rate when used for terrestrial applications.



Efficient photovoltaics: *A University of Texas at El Paso undergraduate, stands next to "Manah," a vacuum system used to fabricate solar cell devices. This research should lead to low-cost flexible solar cells with efficiencies approaching 17 percent.*

Researchers at UTEP are in the early stages of developing a different type of photovoltaic cell expected to compare favorably to existing commercial technology in terms of both performance and cost. These researchers are developing cadmium-sulfide/cadmium-telluride (CdS/CdTe) solar cells on flexible metal-foil substrates. Researchers expect eventually to produce photovoltaics with efficiencies of up to 16.8 percent and costs of under \$1/W.

The CdS/CdTe thin-film (2 to 6 micrometers) solar cells also offer other advantages over current technology. For example, they are lightweight, and are expected to degrade much less than solar cells made from amorphous silicon. And since vacuum evaporation or spraying technologies are used to make the solar cells, researchers project that manufacturing costs will be much lower. Amorphous silicon solar cells require expensive chemical vapor deposition or plasma systems.

Other advantages include thermal control and adaptability. Metal conducts heat better than glass (typically used as a substrate for thin-film photovoltaics) and, therefore, thermal control is easier and less costly. In addition, the substrate is thin, lightweight, and flexible, making it an attractive option for applications where these features are issues. UTEP has developed interface technology which allows for a conducting contact when CdTe is deposited on top of the substrate. Researchers are currently optimizing CdTe film characteristics and the CdTe/CdS junction. UTEP expects to complete a prototype in 1998.

To commercialize this technology, a researcher at UTEP is collaborating with Golden Photon, Inc. (Golden, CO), a photovoltaic manufacturing company. Golden Photon is building a pilot-scale facility to manufacture CdTe panels on glass. UTEP plans to incorporate research into second-generation products at Golden Photon.

BMDO funded research for CdS/CdTe solar cell structures on flexible metal foil substrates at UTEP through the Historically Black Colleges and Universities/Minority Institution program, which capitalizes on specialized technical knowledge found at many of these schools. The National Science Foundation and NASA are also funding the university for related research.

***Award winning breakthrough:** Pictured above is a solar thermal hemispherical dish that uses Thermacore's heat pipes. The heat pipes were chosen, in part, because their high heat flux capability allowed them to perform well in high-temperature applications. They also offer cost and manufacturing advantages.*

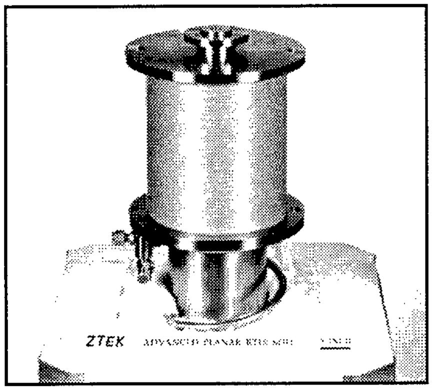
■ Thermacore, Inc.

Thermacore, Inc. (Lancaster, PA), has developed heat pipes that engineers have incorporated into a solar thermal hemispherical dish for utility-scale power generation. Along with Sandia National Laboratories, Cummins Renewable Energy Corporation, and Sunpower, Inc., Thermacore won an R&D 100 award from *R&D Magazine* for the solar dynamic power system using a Stirling-cycle engine. Thermacore is still pursuing solar applications with Cummins Renewable Energy Corporation and Sandia National Laboratories.

Thermacore's heat pipes were selected for the project because they use an innovative porous metal wick made from powders with varying particle sizes. The variation in the wick pore size of the wick structure gives the heat pipes a high heat flux capability. In solar thermal systems and other very high-temperature applications, the coolant in the heat pipe often boils. If the pore size is uniform, the vapor will spread equally within all pores, preventing liquid flow and thereby adversely affecting the performance of the heat pipe. But if the pore sizes vary, the vapor will flow within the large pores, allowing the small pores to facilitate liquid flow. Observing this condition, Thermacore has optimized the distribution of pore sizes in the heat pipe structure so that the small pores still function as the vapor travels in the larger pores. This gives the heat pipe a high heat flux capability, making it ideal for high-temperature applications. In addition, if wire mesh heat pipes were used, they would require 30 or 40 layers of mesh screen, which is costly and difficult to fabricate. Therefore, the porous metal heat pipes provide cost and fabrication advantages as well. They are also easier and less expensive to conform to the special shape of the solar thermal system's hemispherical dish. BMDO funded Thermacore's heat pipe technology through an SBIR project.

■ Ztek Corporation

Ztek Corporation (Waltham, MA) has developed an advanced planar solid oxide fuel cell (SOFC) called the Zirconverter®, ideal for utility-scale electric power generation because of its simple design, low manufacturing cost, and efficient recovery of high quality by-product heat (1,000°C). The company markets a 25-kilowatt (kW) system to generate power and is planning a 250-kW system available in 1998.



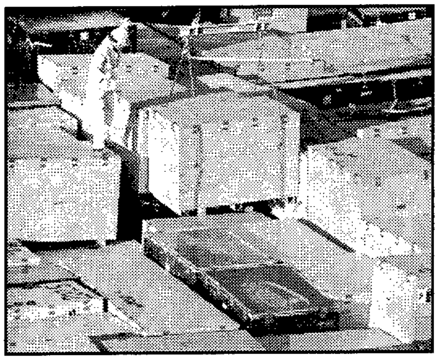
A power-producing alternative: *Z-Tek's solid oxide fuel cell needs no recharging and provides virtually pollution-free power.*

The SOFC can generate electricity using petroleum or nonpetroleum-based fuels and emits little or no pollution. If hydrogen is used as a fuel, its by-products are water and very small amounts of CO_2. The Zirconverter, therefore, can give utilities the flexibility to choose cleaner fuels. With funding from EPRI and the U.S. Department of Energy, Ztek developed a method to combine the Zirconverter with gas turbines, which are widely used in power generation. This approach, known as Internal Thermal Integration (ITI) allows gas turbines to replace combustion chambers with Ztek's clean, efficient fuel cell. The resulting system reduces hardware costs, provides virtually pollution-free power, and increases overall electric efficiency to greater than 70 percent. A utility advisory board chaired by the Tennessee Valley Authority will participate in the development and demonstration of this technology.

BMDO originally funded research at Ztek for advanced planar SOFCs through an SBIR design concept. Ztek's SOFC creates electrical energy through an electrochemical reaction with gaseous fuel and oxidizer. The fuel, usually natural gas, is supplied by an outside source and reacts with the oxidizer in the cell, creating electrical energy and leaving water as a by-product. The SOFC will provide electricity as long as fuel is available, needing no recharging.

Reducing the Impact of Nuclear Waste

Between 1968 and 1994, the 118 light-water reactors in the United States (some of which have been decommissioned) discharged more than 30,000 metric tons of uranium.[13] Of the 110 reactors expected to be in operation by the year 2000, 9 reactors are projected to reach storage capacity before turn of the century.[14] Associated electric utilities will be required to either expand these facilities or find alternative means or sites for storing waste. Additional storage needs raise many economic, regulatory, transportation, and public relations issues, because nuclear wastes are not only highly toxic but also long lasting, with half-lives extending beyond 10,000 years.



***Stacks and stacks:** A worker sets down a metal container of low-level radioactive waste, produced by a nuclear power plant. The disposal facility is the U.S. Ecology waste disposal site, located in Hanford, Washington.*

Nuclear power plants usually store spent fuel at reactor sites in borated water-filled pools; in this way, electric utilities avoid the need to transport the highly toxic material to remote locations and over state lines. For perspective, utilities store about 29,270 tons of this spent fuel at reactor sites, mainly in water-filled pools. They transport the remaining spent fuel to dry storage facilities at independent spent fuel storage installations located in seven Eastern States. (Dry storage facilities store spent fuel assemblies in shielded mobile or stationary containers filled with an inert gas or with air.) In addition, 2,208 high-temperature gas-cooled reactor fuel elements are stored in sites in the Rocky Mountain States.[15] Utilities are looking at various other strategies such as reracking to achieve a higher maximum capacity. Reracking maximizes storage space, making inaccessible slots (spaces that hold assemblies) available. For example, a Southern utility has a licensed storage capacity of 988 assemblies, yet the plant can only use 959 assemblies because of conditions such as piping blockage.[16]

However, there is no available approach to treat spent fuel to make it less toxic or reduce its half-life. With current trends and technology, radioactive spent fuel amounts will increase, remaining in pools and vaults for many, many generations to come.

Funding Technology Innovations

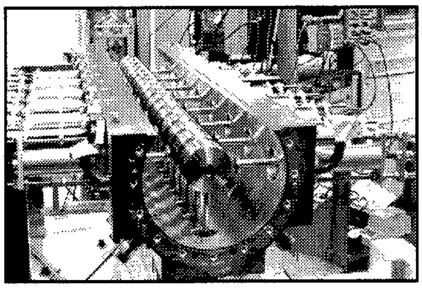
BMDO originally funded particle beam accelerators (electrical devices that accelerate charged atomic or subatomic particles to high energy) as a means to attack enemy booster or re-entry vehicles. Development in this area is being investigated as a way to change nuclear waste to either nonradioactive materials or materials with half-lives of several centuries rather than tens or hundreds of thousands of years.

[13]Energy Information Administration. 1996. *Spent Nuclear Fuel Discharges from U.S. Reactors 1994.* p. xiii.
[14]Energy Information Administration. 1996. *Spent Nuclear Fuel Discharges from U.S. Reactors 1994.* p. xiv.
[15]Energy Information Administration. 1996. *Spent Nuclear Fuel Discharges from U.S. Reactors 1994.* p. xiv.
[16]Energy Information Administration. 1996. *Spent Nuclear Fuel Discharges from U.S. Reactors 1994.* p. 31.

Moving the Technology to Market

■ Los Alamos National Laboratory

Researchers at Los Alamos National Laboratory (LANL; Los Alamos, NM) have developed a design concept called accelerator-driven transmutation technology, or ADTT, to destroy long-lived nuclear waste and weapons-grade plutonium. While the technology is at least 15 years from commercialization, its implicit contributions to this serious waste problem could make a lasting and positive difference. If fully developed, ADTT could reduce the half-lives of radioactive waste to a few centuries, making it easier to design secure storage facilities. ADTT can also produce thermal power (just as in a nuclear reactor) for generating electricity while treating the waste.



Nuclear waste reduction: *Investigating a concept called accelerator-driven transmutation technology, researchers at Los Alamos National Laboratory have been investigating ways to use particle beam accelerators, pictured above, to reduce the impact of nuclear waste.*

One of LANL's ADTT programs called accelerator transmutation of waste, or ATW, treats waste from commercial nuclear reactors. ATW uses neutrons to transmute long-lived fission products and actinides in commercial reactor-spent fuels, which can remain radioactive for up to one million years. Radioactive isotopes of technetium, iodine, plutonium, neptunium, and americium are among those that could be destroyed by the LANL ATW system.

In this technology, accelerators bombard a heavy metal target (such as lead) with an 800- to 1,000-million-electron-volt proton beam. When the proton beam hits the target, it produces an energetic spray of neutrons, about 20 to 30 neutrons per atom in the proton beam. A surrounding blanket of molten salt contains the nuclear material to be transmuted, and graphite, which multiplies these neutrons. This blanket also slows the energy level of the neutrons to increase the probability of transmutation reactions. Materials such as plutonium, waste actinides, or long-lived fission products are continuously introduced into the blanket assembly. Remaining radioactive materials can be separated and re-introduced into the system to further reduce their long-lived radioactivity.

As a side note, researchers at LANL have also investigated accelerator-based concepts for generating electricity, an approach called accelerator-driven energy plants (ADEP). This approach produces significantly less long-lived nuclear waste than conventional nuclear power plants. The laboratory's design concepts rely heavily on particle accelerators. An alternative to conventional nuclear power plants, ADEP transmutes its own long-lived wastes—and uses thorium, a more abundant nuclear fuel.

BMDO funded much of the particle beam accelerator work that has been applied to ADTT. ADTT has since received international attention. The International Science and Technology Center granted LANL a $3-million contract to further develop ADTT to reduce the hazards of nuclear waste and plutonium. In the project, Russian researchers will develop hardware, test stands, and databases for accelerator, target, blanket, and separations systems while LANL will provide management support. In addition, this effort will provide a new nondefense mission for more than 200 former weapons scientists from Russia. The scientific fruits of this collaboration should also advance worldwide efforts to reduce the stockpiles of nuclear weapons materials.

U.S. Electric Utility Actual and Potential Peak Load Reductions in Megawatts[1]

Year	1991	1992	1993	1994	1995	1996 (Projected)	2000 (Projected)
Actual	15,619	17,204	23,069	25,001	29,561	32,627	39,824
Potential	Not Available	32,442	39,508	42,917	47,029	49,192	58,081

[1] Energy Information Administration.1997. *U.S. Electric Utility Demand Side Management 1995.* January, p. 33.

▲ ***Demand side management:*** *According to the Energy Information Administration, U.S. electric utilities have the potential to save more than 58,000 megawatts from their peak load by the year 2000.*

Electric utilities face varying load management challenges depending on where they reside, the politics of their state or region, and the capacity of their power plants. Therefore, these power producers often implement special programs so that they exert more control over load demand.

One issue revolves around electric utilities' frequent need to reduce peak power demand. Power requirements often fluctuate in both daily and seasonal cycles. So, for example, electricity demand usually peaks in the early afternoon and decreases at night. Unless there is an unusually harsh winter, it peaks annually in the summer and decreases in the fall. These peaks and valleys often cause inefficiencies because of the time and expense involved in bringing power plants up and down. To allay such problems, electric utilities often employ demand side management (DSM) programs that reduce these curves. The Energy Information Administration defines DSM as the planning, implementation, and monitoring of activities that encourage consumers to modify their levels and patterns of electricity consumption.[2] For perspective, electric utilities in 1995 spent about $2.4 billion on DSM programs in the United States.[3] Such efforts take many shapes and sizes, depending on the utility's electricity production requirements, state incentives, and customers. They generally, however, fall into two categories: energy efficiency and load shifting.

Energy efficiency became a major issue for electric utilities in the 1970s because of factors such as rising capital costs for plant construction, concern about energy resources, and public interest in energy conservation. Since then, the Federal government has implemented several regulations to encourage energy efficiency at the electric utility level. These include the Energy Conservation and Production Act of 1976, the National Energy Conservation Policy Act of 1978, and the Energy Policy Act of 1992. All have an impact on related energy-efficiency programs and efforts.

Energy-efficiency programs, when effective, reduce peak loads through lower electricity demand. Utilities with increasing demand that approaches capacity may find these programs to be more cost effective than building new power plants. Energy efficiency also provides environmental and energy resource benefits and some states may encourage electric utilities to implement energy-efficiency programs through incentives. The electric utilities may not initially benefit from decreased sales because their peak load demand is already manageable; however, the incentives help offset the costs in lost electricity sales.

In load shifting, electric utilities transfer load requirements from peak periods to off-peak periods; it can be accomplished either through DSM or at the central station power level. There are several strategies for shifting loads, such as by encouraging residents through

[2]Energy Information Administration. 1997. *U.S. Electric Utility Demand-Side Management 1995.* January, p. 1.
[3]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 83.

financial incentives to perform electricity-intensive tasks during off-peak periods. Advanced technology in energy storage, while not fully developed, could also play an important role. It could store excess electricity at night and then release reserves during peak periods.

Another load management approach does not reduce peak loads at all, but rather increases electricity sales. This approach, called load building, encourages industries to use electrical equipment, or electrotechnologies. Some incentives may be inherent in the technologies themselves because the technologies, for example, may be more environmentally friendly approaches to chemical processes. Or, they may be more cost effective to the manufacturer.

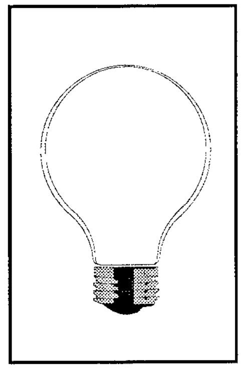
BMDO has funded technology development in several areas such as power, optoelectronics, magnetic bearings, and materials that may assist the electric utilities in energy efficiency, load shifting, and load building applications. These technologies, as applied to the electric utility industry, include holographic films to increase the energy-efficiency of windows, solid-state generators to produce electricity in residences, and flywheel technologies for storing electricity on a large and small scale. This section covers the following topics:

- Reducing Peak Loads Through the Buildings Sector
- Load Building Technologies for Industries
- Shifting Electricity Loads at Central Stations

Reducing Peak Loads Through the Buildings Sector

To perform demand side management (DSM), electric utilities often manage loads and increase energy efficiency at the customer level. The residential and commercial sectors combined (sometimes referred to as the buildings sector) offer enormous opportunities in terms of peak load reductions. For perspective, the building sector consumed roughly 1.829 trillion kilowatt-hours (kWh) and accounted for $148 billion in revenue for U.S. electric utilities in 1994.[4]

One way to reduce peak load is to provide incentives so that customers invest in energy-efficient technologies. Electric utilities sometimes encourage such technologies through their DSM programs. For example, nationwide, roughly 275 electric utilities in the United States sponsored energy-efficient lighting programs targeted at the commercial sector alone, and 246 utilities sponsored similar programs in the residential sector.[5] The challenge has been in finding lighting technologies that have quick payback periods (periods in which the energy cost savings off set the added cost in investment).



Less electricity for lighting: *Nationwide, roughly 275 electric utilities in the United States sponsored energy-efficient lighting programs targeted at the commercial sector alone, and 246 utilities sponsored similar programs in the residential sector.*

Another way that electric utilities can reduce peak loads, and also enhance customer service, in the buildings sector is through alternative methods for generating or storing electric power in homes and offices. While this is often done at a manufacturing and institutional level through cogeneration, small-scale power generation in homes and commercial buildings has been limited by factors such as noise, cost, maintenance, and emissions. New technologies are emerging, however, that challenge electric utilities to take a new perspective on power generation at a smaller level.

Funding Technology Innovations

BMDO has funded several technologies that can assist utilities in their promotion of DSM-related technologies. For example, BMDO funded holography work through its SBIR program for a solar holography technology, which spectrally separates sunlight. BMDO initially pursued this technology as a solar cell concentrator for generating electricity in space. Industry is now incorporating it into a daylighting technology that can control how much sunlight enters a window.

BMDO also funded work in high-energy electrical storage devices based on thermopile technology (see below for a detailed description). This work has translated into a low-cost, compact, quiet power generator for residential and commercial power generation.

[4]Energy Information Administration. 1995. *Electric Sales and Revenue 1994.* November, p. 5.
[5]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 84.

Based on work conducted on several BMDO SBIR contracts, vibration control technology has been combined with magnetic bearings to eliminate vibration and reduce friction in flywheel energy storage devices. This technology has been further developed as an energy storage technology for commercial use.

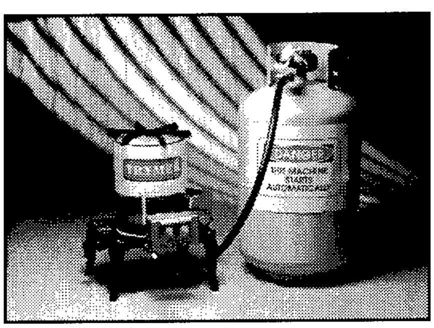
Moving the Technology to Market

■ HOLOS Corporation

The HOLOS Corporation (Fitzwilliam, NH) is preparing to produce holographic films for windows to improve the energy efficiency of buildings. When applied to glazing, the films will track and control the amount of sunlight that enters buildings. Users can adjust them to either allow more sunlight to enter the room, thereby lowering lighting and heating costs, or block sunlight from entering the building, thereby lowering cooling costs. Holographic-coated windows should reduce energy bills enough to pay back their cost to the consumer in less than one year.

Dr. Jacques Ludman, President of Northeast Photosciences (Hollis, NH), is one of the two founding scientists of HOLOS and serves as its chairman of the board. HOLOS markets and manufactures products and technology partially based on patents and innovations that Dr. Ludman developed. The facility has over 75,000 square feet of floor space and two fully equipped clean rooms. HOLOS will be the first supplier of mass-produced color holograms. Other technologies developed by Northeast Photosciences and nearing production at HOLOS appear on page 51 of this report.

Noiseless and compact: *Pictured below is a prototype of the Trymer Company's low-cost, compact 3-kW unit. Projected to cost roughly $500, the generator can be configured to convert heat from almost any type of fuel into electricity.*



■ The Trymer Company

The Trymer Company (Leander, TX) is in the final stages of producing a small (roughly 3 kilowatts [kW]), noiseless generator called the Trymer 5000. Projected to cost roughly $500, this portable unit can provide either alternating current (ac) or direct current (dc) electricity as back-up power for homes, businesses, and sites in remote locations. While designed to operate on propane fuel, other types of fuel, such as wood, can be used. Water supplies the unit's cooling needs.

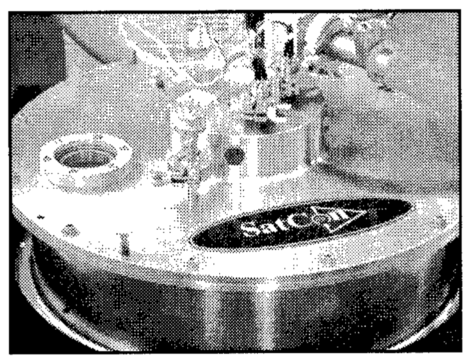
The company's generator is based on a century-old technology called the thermopile. A thermopile is an array of thermocouples—a thermocouple being a pair of dissimilar metallic wires joined at one end. Two thermocouples connected to each other with the two junctions at different temperatures produce a voltage difference often used to measure local temperatures precisely. By connecting many pairs of thermocouples in series, the thermopile can measure small temperature excursions arising from exposure to infrared radiation. However, when deliberately exposed to a large temperature excursion, the thermopile can also generate a large current.

Trymer is taking an integrated circuit approach to this concept to maximize the number of junctions and bring them closer to each other. The denser thermopile array was formed into a ring with half the junctions sinked to a chill block, and the alternate junctions exposed to a heat source. Since each pair of thermocouples serves as a potential source of current, the circular array produces and sustains internal currents up to 2 million amps. Much of the energy content of the device is in the induced magnetic field of up to 26 Tesla.

Further into the future, Trymer is investigating a 60-MWh magnetic energy storage system for electric utilities. This battery-like device could allow utility companies to store some of the electricity produced at night and use it during the afternoon peak, a strategy called load leveling. Trymer is researching this concept under contract with the National Science Foundation.

■ SatCon Technology Corporation

SatCon Technology Corporation (Cambridge, MA) is developing a commercially available flywheel energy storage (FES) system that can assist electric utilities in load shifting and power quality requirements. A single device can supply 1 kW of power for about two hours, which is enough to provide short-term back-up power for appliances or lighting. If used for load leveling, the FES could be installed at a customer's home or commercial site. It could store electric power (as kinetic energy) overnight during off-peak periods and then supply it to an electrical appliance during peak periods. The device can also stabilize power delivery during brief disruptions or voltage sags, thereby enhancing power quality for commercial (and industrial) customers where power quality is essential.



Small-scale storage: *SatCon's flywheel energy storage can supply 1 kW of power for about two hours, and could be installed at a customer's home or commercial site.*

Key attributes of SatCon's flywheel is a projected life cycle of over 10,000 recharges, a shelf-life of over 20 years, and a recharge period of three hours. In addition, the company's FES does not rely on chemical reactions to produce electricity, unlike batteries, and therefore has environmental advantages in terms of disposal. In addition, it only requires maintenance once every seven years.

Able to rotate at high speed and store large amounts of energy, the FES system relies on an electric drive to accelerate the flywheel, an action which causes energy to be stored in the spinning wheel. When the flywheel spins down, the rotating energy drives a generator, and releases electricity.

Used in mechanical work, the flywheel has been available for hundreds of years; however factors such as size, efficiency, and cost limit its use as an energy storage device. Recently, advanced research in magnetic bearings, as funded through the BMDO SBIR program, has led SatCon to a commercially viable FES for small-scale storage applications. SatCon's magnetic bearings use active controls to balance the forces. In addition, they are frictionless, which increases their lifetime (and hence, that of the flywheel) and eliminates the need for lubricants.

Load Building Technologies for Industries

Thirty years ago, manufacturers heavily depended on electricity for their processes, and to a large extent, they still do. The industrial sector represented over $48 billion in revenues for electric utilities nationwide.[6] However, due to the energy crisis of the early 1970s and similar energy concerns of the late 1970s, manufacturers have begun to pursue energy-efficient strategies to control and, then later, reduce production costs. These energy-efficient strategies usually reduce the industrial energy intensity, or the ratio of energy used (usually converted to British thermal units) to the dollar value of product shipments. While energy intensity in the manufacturing subsector did slightly increase between 1988 and 1991, it has generally declined since the mid-1970s, dropping almost 28 percent between 1977 and 1991.

Electric utilities spent about $42.1 million on load building programs in 1994—an expenditure on the rise.

Therefore, some utilities with high load capacities and waning electricity sales to the industrial sector have developed load building programs to encourage industries to increase their use of existing electric equipment or to invest in new electric equipment. For perspective, electric utilities spent about $42.1 million on load building programs in 1994. This expenditure is projected to rise to $69.7 million in 1999.[7] The utilities' challenge is to find electrically driven processes that offer significant advantages over existing manufacturing processes. These so-called electrotechnologies usually offer environmental, performance, and cost benefits over existing nonelectrically driven technologies.

Materials processing is one area where electrotechnologies offer many benefits. Using high power levels, many industries can produce or treat materials at a higher quality than those using existing processes. In many cases, these materials processing electrotechnologies also eliminate many of the environmental issues revolving around chemical waste disposal normally associated with electroplating. In addition, such processes can benefit the utility industry itself; they can be used to treat or form turbine blades or other power plant components to protect them from corrosion.

Funding Technology Innovations

BMDO has funded significant research and development in power and materials process electrotechnologies that may offer many performance and environmental advantages over other manufacturing processes. For example, two projects are using BMDO-funded technology in environmentally friendly processes for hardening materials. One project employs technology from BMDO-funded work initially performed with the U.S. Department of Energy on Repetitive High Energy Pulsed Power Program (RHEPP) accelerators. These accelerators produce both high average power and short duration pulses, which would provide a beam to destroy space-based ballistic missiles. Another project, called plasma source ion implantation, employs the design of a modulator that controlled

[6]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 21.
[7]Energy Information Administration. 1995. *Electric Power Annual 1994, Volume II.* November, p. 83.

the voltage output from the power source of the BMDO-funded Ground Test Accelerator. The Ground Test Accelerator is a cryogenically cooled accelerator built as a follow-on to the Beam Experiment Aboard Rocket (BEAR) project. The intent of the Ground Test Accelerator project was to develop (on the ground) a model of a space-based neutral particle beam weapon.

Another materials technology, called dynamic magnetic compaction (DMC), employs BMDO-funded electromagnetic power technology for railgun research through the SBIR program. Railguns were envisioned early in the BMDO (then the Strategic Defense Initiative Organization) research program as orbiting kinetic energy weapons. The orbiting defensive weapons, if fully developed, would shoot a small projectile at a missile in its mid-course trajectory. This research is being applied to DMC, which makes parts from powder. The parts are dense enough to provide the durability required for automotive parts. DMC should increase assembly-line efficiency while also producing a higher-quality product.

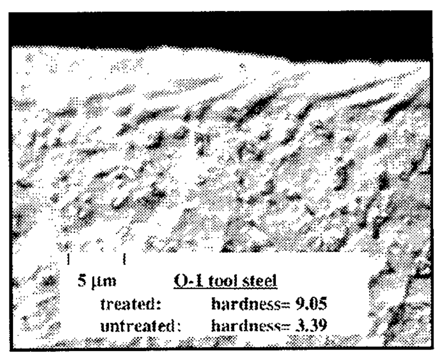
In another project, the BMDO SBIR program funded Combustion Chemical Vapor Deposition, or CCVD℠, to benefit future BMDO systems. The system can produce defense and commercial' components with improved mechanical wear resistance, chemical resistance, and thermal protection. The BMDO-funded project focused on developing thin films for catalytic applications, such as fuel cells, and heat exchangers.

Moving the Technology to Market

■ Sandia National Laboratories; QM Technologies, Inc.

Licensing technology from Sandia National Laboratories (Albuquerque, NM), QM Technologies, Inc. (QMTI; Albuquerque, NM), is marketing an electrotechnology called ion beam surface treatment (IBEST). IBEST applies ion beams that rapidly melt and resolidify the surface area of objects to increase their hardness. An improvement over electroplating, IBEST does not produce waste and costs less. Initial experiments indicate that the accelerator-driven ion beams could treat metal, ceramic, glass, or plastic surfaces.

Power-based process for materials treatment: *IBEST is an electrotechnology that significantly increases the hardness of machined parts.*

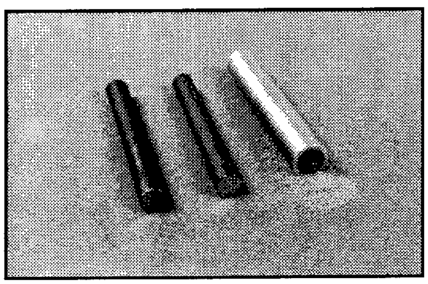


The IBEST process uses high-energy, pulsed (typically less than 200 nanoseconds) ion beams to heat material surfaces. Because of the pulsed nature of the beam and the 1 billion°C per second cooling rates associated with the process, only thin surface layers of 2 to 20 micrometers are rapidly melted and cooled. Therefore, the process can form amorphous and nanocrystalline grain layers without altering the atomic composition of the treated part. These treated surface layers have demonstrated better surface hardness; higher quality surface finish (micro-cracks removed); removal of oxides and surface contaminants; and increased corrosion resistance in steel, stainless steel (including weld regions), and aluminum. The degree and type of improvement depend on the exact material that technicians are treating.

Funded by BMDO and the U.S. Department of Energy, the Repetitive High Energy Pulsed Power Program (RHEPP) accelerators combine high average power and short duration pulses required for high-efficiency IBEST systems. QM Technologies plans to develop prototype commercial IBEST processing equipment by mid-1997. This activity is through a cooperative research and development agreement (CRADA) with Sandia and ongoing relationships with Cornell and Applied Pulsed Power (Ithaca, NY).

■ IAP Research, Inc

IAP Research, Inc. (Dayton, OH), is in the early stages of developing a materials production technology called dynamic magnetic compaction (DMC). When fully developed, DMC can produce industrial parts with demanding performance requirements. For example, automobile manufacturers use the technology to produce power train gears. DMC should eliminate the need for post machining from traditional forging and casting while fabricating materials much stronger than those made by existing powder metallurgy processes.



Industrial parts production: *IAP Research's process has been used to form metal rods, as shown above. Powder is loaded into a copper tube (right) and the compaction process forms the powder into a high-density rod (left).*

A process for manufacturing materials, powder metallurgy compacts metal powders into various smooth shapes, eliminating the need for polishing and finishing. However, this process has not yielded the densities required for rugged, high-performance components. The more demanding components are still cast or forged, making them costly to manufacture. DMC makes parts from powder dense enough for use in automobiles. The process speeds up assembly-line manufacturing while also improving the quality of the parts.

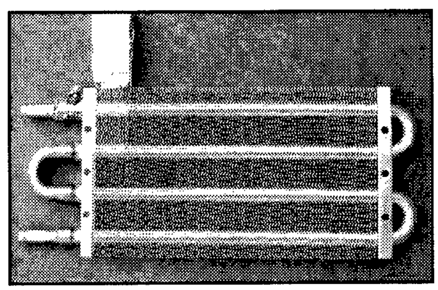
In DMC, high currents are passed through the compactor coil using a power supply system. The powder material is enclosed in a confining container and placed at the center of the compactor coil. For electrically nonconducting powders, the confining container must be conductive; for conductive powders, this restriction does not apply. The currents in the compactor coil generate a magnetic field, which produces magnetic pressure on the powder, consolidating the powder. This pressure is directed radially inwards on the powders. While conventional techniques apply pressure from the top and the bottom, the IAP Research method applies force from the outside to the inside, along the entire length of the part.

Using DMC, researchers at IAP Research believe manufacturers can make a complete gear, including the teeth, in less than a second. Starting with steel in powder form, the IAP Research-led joint venture will use high-pressure pulses generated by an electromagnet to compress the powder into a die to make a solid part. The pressures equal those under a 4,000 pound automobile supported on a three-penny nail. A second step in the process sinters or "bakes" the part to strengthen it.

To bring the technology to market, IAP Research is leading an $8.4 million cost-shared Advanced Technology Program project, which the National Institute for Standards and Technology awarded to further develop DMC. IAP Research has teamed with General Motors Powertrain Division and Zenith Sintered Metal Products; the team will contribute $4.3 million towards the project and is focusing on complex automotive transmission components. IAP intends to produce and sell the electromagnetic parts-making equipment to car parts manufacturers such as its joint venture partner, Zenith Sintered Metal Products, which will then mass produce and sell parts to General Motors and other major manufacturers.

■ MicroCoating Technologies

MicroCoating Technologies (Atlanta, GA) researchers have developed a low-cost, flame-assisted thin-film coating process that deposits a wide spectrum of materials in open atmosphere conditions. Unlike other low-cost deposition technologies, this process, called CCVD℠ (short for combustion chemical vapor deposition), can produce the same high-quality coatings as current chemical and physical vapor deposition technologies. It also can coat objects with large or irregular surfaces, such as assembled parts that technicians would find difficult to place inside a traditional coating chamber.



Cost-effectively coating detailed objects, large and small: *Above is a radiator part coated using the CCVD℠ process. The open-environment process not only can coat large parts, but also highly intricate ones.*

The electrically driven technology is more energy efficient than competing processes, and would normally be regarded as a technology for peak shaving, and still could be marketed as such; however, because of its low cost, wide variety of uses, and its less polluting characteristics, CCVD is expected to be used throughout the industrial sector for applications where coatings would normally not be pursued. This additional user base should add revenues for electric utilities.

With the CCVD technology, a starting chemical precursor is dissolved in a liquid that acts as the combustible fuel. This solution is atomized and then combusted in the flame. The heat from the flame provides the energy required for the precursors to react and deposit onto the substrate. Users can perform the CCVD process at ambient temperatures without a costly reaction furnace or vacuum chamber. The reduced requirements provide significant cost advantages over traditional thin-film processes, and enable technicians to continuously feed materials into the deposition zone.

So far, MicroCoating Technologies has used the CCVD process to deposit over 40 materials on many different substrates. For example the process can deposit metals, ceramics, and composites onto metal, ceramic, glass, and even some plastics. It can coat automotive parts; heating, ventilating, and air conditioning (HVAC) equipment; production tools; mechanical dies; architectural glass; ceramic fibers; turbine engines; and x-ray generators. A variety of optical, thermal, and protective barriers are also possible.

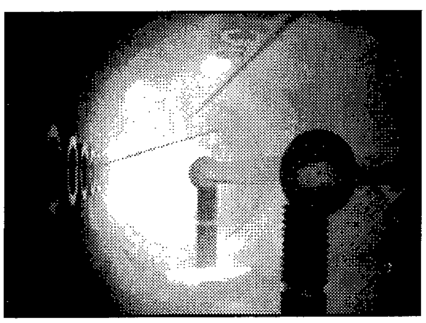
The CCVD process also uses inexpensive chemical precursors that cost up to 100 times less than the high-purity, high vapor pressure ones used in conventional CVD chambers. Using these precursors, the CCVD technology can precisely control the chemical

composition and physical properties of coatings, allowing, for example, multiple layers of different materials to be deposited onto a single surface. This control gives the CCVD process a big quality advantage over other open-atmosphere, thick-film processes that are comparable in cost. Examples include laser ablation, oxy-acetylene torches, or electroplating. In addition, simple and versatile chemical precursors allow technicians to apply a wide spectrum of materials onto a variety of substrates.

While potential applications remain diverse, the company has recently worked extensively with the automotive industry, coating prototypes for automotive parts. In three examples, MicroCoating Technologies has successfully applied (1) catalytic coatings on various engine components, (2) corrosion and oxidation-resistant coatings on engine parts, and (3) thermal barriers on engine parts. In addition to pursuits in the automotive area, MicroCoating Technologies is working with a company in Western Europe to treat HVAC engines for corrosion resistance. Some of MicroCoating Technologies' customers include GM Delphi, Caterpillar, and AlliedSignal.

■ Los Alamos National Laboratory

Los Alamos National Laboratory (LANL; Los Alamos, NM) has helped to develop a manufacturing process called plasma source ion implantation (PSII) to make harder, more durable, and longer-lasting parts for a variety of machinery applications. Rather than coating the material, which manufacturers must toughen to survive severe environments, this process changes its surface layer. The electrotechnology can harden components for automobiles, aircraft, power plants, and prosthetics. In addition, production machine parts can be treated, increasing their service lives for manufacturing.

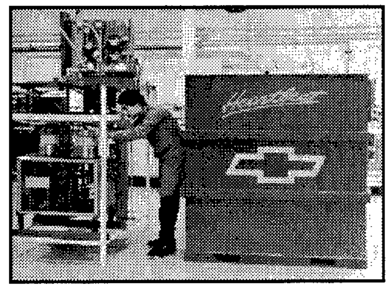


A view inside the chamber: *Rather than coating the material, PSII modifies its surface layer. In a simulation pictured above, a cylindrical aluminum pipe is implanted with nitrogen.*

Since PSII is not a coating, adhesion and delamination are not concerns. As compared to line-of-sight implantation processes, it costs less and has a higher average current (1.00 ampere versus 0.03 amperes), permitting much faster implantation. It also does not require masking of expensive fixturing to manipulate nonplanar parts, and can evenly treat odd-shaped items such as power tools, door locks, or drive trains. In addition, PSII does not produce a chemical waste stream, unlike electroplating technologies.

In PSII, a low-pressure gas, such as nitrogen, is injected into a steel vacuum chamber containing the material to be hardened. The nitrogen is ionized into a plasma using oscillating radio frequency waves to strip electrons from the gas atoms. The system exposes the material to short pulses of negative voltage. Positively charged ions are accelerated toward the negatively charged material, and simultaneously bombard the material from all sides. The ions penetrate and modify the near-surface layers of the material. Using this process, manufacturers can improve metal and polymer surfaces.

The PSII concept was developed at the University of Wisconsin-Madison and was scaled up to a small manufacturing prototype in a $14-million, three-year CRADA between LANL and General Motors Research Division (GM: Warren, MI), with assistance from the University of Wisconsin.



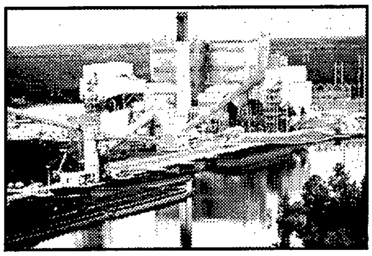
From a government laboratory to the commercial marketplace: *PSII can be used in several commercial applications, including automotive applications, as pursued by General Motors.*

In the CRADA, GM focused on applications to improve automotive manufacturing. LANL provided much of the equipment including a compact power source, or modulator funded by BMDO for the Ground Test Accelerator, and worked with the University of Wisconsin to explore the process' fundamental physics and improve the concept. The CRADA team targeted two applications: nonferrous automobile parts and ferrous tools (e.g., punches and drill bits).

A consortium of 14 organizations was formed to scale up the PSII process for large-scale production. In late 1995, the team won a $15.5 million cost-shared Advanced Technology Program award from the National Institute of Standards and Technology. The consortium is working to alter the power source to meet various manufacturing scenarios and to demonstrate that high-volume manufacturers can use the process. The project is administered by the Environmental Research Institute of Michigan and includes A.O. Smith Corporation; Empire Hard Chrome, Inc.; General Motors; Harley-Davidson, Inc.; and Kwikset Corporation, among others.

Shifting Electricity Loads at Central Stations

The cycles for peak demand of electricity challenge many utilities, especially in geographic areas with growing populations and industries. The seasonal and daily cycles of peak power demand usually occur respectively in the summer and in the middle of the day—but issues such as weather can alter these trends. Electricity produced off-peak is often wasted, and usually older power plants or those that cost more to operate are brought on- and off-line. Such operating conditions often result in decreased efficiencies in both energy and manpower. Therefore, electric utilities have developed peak clipping and load shifting approaches to allay this problem.



Large-scale storage: *By storing power produced at central stations during off-peak periods and tapping into the supply during peak hours, utilities could avoid the costly roller-coaster effect of load swings.*

This subsection focuses on load shifting approaches involving energy storage. It should be noted that electric utilities shift electric loads in other ways as well. One way is through direct load control, whereby an electric utility can interrupt a consumer's load, such as a water heater, during peak periods. This technique is used with the customer's permission. Or an electric utility might impose aggressive time-of-use rates that encourage consumers to shift their hours for energy consumption to off-peak periods. Using another approach, electric utilities might establish agreements with industrial customers to shift some of the manufacturing operations to off-peak hours. In most cases, such strategies depend on modified customer behavior.

A more centralized approach, large-scale electricity storage does not require customer participation. If fully developed, electric utilities could store electricity produced at central power stations during off-peak periods and then tap into the stored supply during peak periods. In this way, the utility could avoid the roller coaster affect of load swings, preventing the need for powering plants up and down, and generating electricity that it ultimately wastes.

However, with the exception of stored pumped hydroelectric power, electric utilities generally do not produce and store large amounts of energy for later use. Storage technologies, such as flywheel technologies and superconducting magnetic energy storage (SMES) could potentially provide many economic and environmental benefits through increased efficiencies. The challenge has been in cost-effectively expanding such technologies for large-scale utility-level applications.

Funding Technology Innovations

BMDO funded energy storage-related technologies that may help utilities address their load-leveling concerns. For example, during the mid-1980s, BMDO funded university-based pulsed power research for electromagnetic launchers. This technology, called the air-core Compulsator, is a pulsed alternator designed to accelerate projectiles to hypervelocities in electromagnetic guns. Advances in this area have led to flywheels that may someday be used for load leveling.

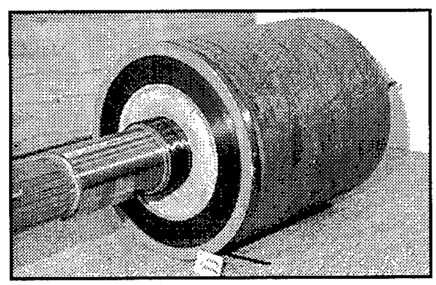
In addition, BMDO funded work in superconducting magnetic energy storage (SMES) to provide sudden bursts of energy for a ground-based laser. While near-term developments address smaller scale applications such as supplements to flexible alternating current transmission systems (FACTS), further into the future utilities can potentially use these systems for load leveling. For more information on SMES, see page 19.

Other BMDO-funded energy storage technologies, such as batteries and capacitors, that may someday be expanded for electric utility applications, are described in another publication, Energy Storage Technology, developed for the BMDO Technology Applications program. Readers can contact the National Technology Transfer Center, Washington Operations, to obtain a copy of the report (see back cover of this report).

Moving the Technology to Market

■ Center for Electromechanics at The University of Texas at Austin

The Center for Electromechanics at The University of Texas at Austin (CEM–UT; Austin, TX) through BMDO funding, has developed the air-core Compulsator, a concept that has advanced the design and fabrication of CEM–UT's composite energy storage flywheels. Flywheels use a rotating mass to store and deliver energy. In one of its efforts, the university is further expanding on this technology with sponsorship through the Texas Energy Coordinating Council. The two groups are building a team of electric utilities to address load-leveling applications.



Advances in energy storage: *CEM–UT's composite flywheel is an energy storage technology that may benefit the utility industry in applications such as load leveling. Low life cycle cost and improved efficiency are two of its advantages.*

Several years ago, CEM–UT invented a technology called the Compulsator, a pulsed alternator designed and rated for high-current repetitive duty; it converts rotational mechanical energy into an electrical pulse or train of pulses. Engineers designed the machine to match a specific load, eliminating any intermediate pulse conditioning or switching. It combines the kinetic energy characteristics of a flywheel with the electrical energy generation characteristics of a generator. When excess electrical power is available, the Compulsator drives the flywheel. When an electrical energy deficit is sensed, the flywheel delivers some of its kinetic energy to the magnetic core, generating electricity. A compensating winding, an eddy current shield, and a specifically designed armature reduce internal impedance for high pulsed-power generation, and provide a variable internal inductance for optimum pulse shape. BMDO funded CEM–UT to develop an air-core Compulsator, replacing iron with advanced high-strength composites, now used in CEM–UT's flywheel developments. While the project for BMDO was never completed, the materials research has led to better flywheels.

CEM–UT has also been developing similar flywheels for hybrid electric vehicles in a project with Defense Advanced Research Projects Agency (DARPA). While the flywheels are smaller than those required for electric utility load-leveling applications, the research represents a building block toward utilities' large-scale requirements. These flywheel batteries will have energy densities of 30 watt-hours per kilogram and power densities of

CEM–UT has also developed a storage device being investigated for power averaging and conditioning.

1,600 watts per kilogram. The power density is four times higher than the long-term goal for batteries set by the U.S. Advanced Battery Consortium, while the energy density is comparable to today's rechargeable batteries. Through the DARPA project, CEM–UT is also developing high-speed flywheel batteries for electric transit bus and locomotive propulsion and is pursuing large flywheel batteries for utility power management (such as would be required for practical electric vehicle recharge stations). Other participants include the State of Texas; AlliedSignal Aerospace; Motor Dynamics, Inc.; AVCON; Central and Southwest Utilities; and the Houston Metro Transit Authority.

On a side note, researchers at CEM–UT also developed a rising frequency pulse generator, which utilities are investigating for use in power averaging and conditioning devices because of the device's storage capacity. In the rising frequency pulsed-power generator design, both the stator and rotor spin and store energy. This feature improves the magnetic coupling between the two components, increasing energy storage density over conventional machines. Researchers considered several rotating shell designs, with emphasis on strain-matched, end-plate, and bearing-housing structures. This generator led to a new compulsator concept used in a 20-megajoule kinetic energy electromagnetic gun for the U.S. Army. The 1,800-kilogram compulsator that powers this system can store 230 megajoules. These military applications demonstrate the storage capabilities of the technology.

The incorporation of advanced technology into competitive industries is a forward-looking approach; it allows businesses to race miles ahead of competition; it allows the United States to maintain economic competitiveness in a global market; and, in many cases, as often felt in the power industry, it improves the quality of life for millions of Americans.

BMDO, which has funded some of the most advanced technology in the world, welcomes industry to work with technology developers in an effort to move its defense-funded innovations into the private sector. Your interaction with small and large businesses, universities, and Federal laboratories will be essential in accessing advanced technologies mentioned in this report.

We at the BMDO Technology Applications program welcome the opportunity to exchange information and comments about this report. We also offer other special reports and publications, such as a quarterly newsletter, free of charge, highlighting technologies that relate to the electric power industry and many other business sectors in the United States. Please feel free to contact us at the following address:

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■ **Coleman Research Corporation** *(page 37)*
Technology: Decentralized square root information filter
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■ **ENTECH, Inc.** *(page 52)*
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■ **ERG Systems, Inc.** *(page 33)*
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■ **Golden Engineering** *(page 30)*
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■ **Harris Corporation** *(page 15)*
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■ **Honeywell, Inc.** *(page 34)*
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■ **IAP Research, Inc.** *(pages 18, 66)*
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■ **Illinois Superconductor Corporation** *(page 17)*
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■ **Integrated Applied Physics, Inc.** *(page 46)*
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■ **Intelligent Automation, Inc.** *(page 39)*
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■ **Liberty Technologies, Inc.** *(page 29)*
Technology: RADView™
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■ **Litton Guidance and Control Systems** *(page 24)*
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■ **Los Alamos National Laboratory** *(page 57)*
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■ **NETROLOGIC** *(page 38)*
Technology: Neural networks and genetic algorithms
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■ **Northeast Photosciences** *(pages 51, 62)*
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■ **On-Line Technologies, Inc.** *(page 44)*
Technology: Multi-gas analyzer
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■ **Pacific Advanced Technology, Inc.** *(page 44)*
Technology: Image multispectral sensor
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■ **QM Technologies, Inc.** *(page 65)*
Technology: Ion beam surface treatment
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■ **Quantex Corporation** *(page 29)*
Technology: RADView™
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■ **SatCon Technology Corporation** *(page 63)*
Technology: Flywheel energy storage system
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■ **Sensors Unlimited, Inc.** *(page 31)*
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Technology: Trymer 5000 noiseless generator
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■ **University of Rochester** *(page 21)*
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